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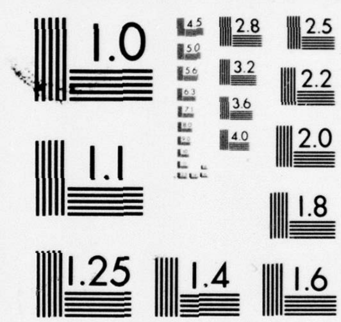

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Technical Memorandum 29-76

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GUIDE FOR OBTAINING AND ANALYZING HUMAN PERFORMANCE DATA IN A MATERIEL DEVELOPMENT PROJECT

Barry L. Berson

William H. Crooks

September 1976

Approved for public release; distribution unlimited.

U. S. ARMY HUMAN ENGINEERING LABORATORY

Aberdeen Proving Ground, Maryland

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This report contains guidelines for conducting, analyzing, and reporting HFE tests according to the specifications of DI-H-1334A. This report was developed for contractor HFE personnel, contract monitors, and program managers. Chapter 2 presents guidelines for HFE personnel on how to conduct HFE tests according to DI-H-1334A requirements. Chapters 3 and 4 are detailed examples of HFE test reports of systems in the Experimental → (over)

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Prototype and Advanced Development Prototype stages of development, respectively. These sample test reports illustrate the contents and level of detail required in DI-H-1334A test reports. Chapter 5 describes how the data collected in HFE tests can be used to increase overall system reliability and effectiveness, when to perform the HFE tests during materiel system development, and how to minimize problems that can occur in HFE tests.

Technical Memorandum 29-76

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PREFACE

Grateful acknowledgement is made to the personnel of the TACFIRE Field Office, U.S. Field Artillery School, Ft. Sill, Oklahoma who provided generous cooperation in the evaluation of the Communication Control Unit. Particular appreciation is extended to Mr. B.J. Hill and to Mr. Joe Dunn who provided much technical support.

Appreciation is extended to the personnel of Teledyne Ryan Aeronautical, San Diego, California for their support of the evaluation of the proposed Compass COPE Ground Control Station. Special recognition is given to John Bunganich, Sherm P. Congdon, W.O. Evans, and Art A. Rutherford for their extensive efforts and generous cooperation.

Mr. John L. Miles, Jr., Chief, Human Engineering Laboratory Detachment, US Army Materiel Systems Analysis Activity, was the scientific monitor of the contract. We acknowledge the support and meticulous guidance he provided throughout the program.

Editor's Note

Army contract data item description DI-H-1334A, entitled "Report of HFE Test" is referred to throughout this report. That data item description has recently been republished as Department of Defense contract data item description DI-H-7058.

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GUIDE FOR OBTAINING AND ANALYZING HUMAN PERFORMANCE DATA IN A MATERIEL DEVELOPMENT PROJECT

INTRODUCTION

Background

Although there are some notable exceptions, there is a recognizable trend upwards in the cost and complexity of most new military hardware. Each expensive new system that fails in the field to meet its expected standards of performance (or is found by operational tests to have significant use problems) testifies to deficiencies in the techniques of engineering management under which it was produced. Certain recent programs have shown that early design mistakes -- particularly those which affect human performance requirements within the system -- can remain undetected until quite late in development. Decreasing amounts of research and development funds available for each project, plus increasing public interest in the Defense Department's materiel acquisition process, have intensified the search for management techniques whose employment will yield an improvement in system performance (38, p.1).

In the late 1960's, it came to the attention of certain Defense Department managers that the unsatisfactory performance record of certain systems somehow involved the personnel who had to operate and maintain them. An increased emphasis on "human factors" was directed for new systems under development. This emphasis produced some new regulations and policies and several new contract data items. One of these, Data Item 1334 (DI-H-1334), entitled "Report(s) of Human Factors Engineering Test," was initially intended to support then-Secretary of Defense Laird's policy of "fly before you buy" by identifying early in the development cycle potential man-machine interface problems which might ultimately reduce system effectiveness or reliability.

Historically, the discipline of human factors engineering (HFE) has been handicapped in identifying such problems because there was not enough access to drawings and models during the early design stages. This lack of access, often founded in cost and schedule constraints, has increasingly come to be viewed as counterproductive. The Army spends far more money in product improvements, retrofits, upgrading personnel aptitude requirements, and lengthening training than it would have spent conducting human engineering tests and requiring design changes during original prototype development. Consequently, DI-H-1334's purpose, in both exploratory and advanced development contracts, is to identify problems sufficiently early to permit their solution by contractor's designers as an integral part of early development.

Following the introduction of DI-H-1334, several revisions were identified which would more clearly define the task performances to be observed and clarify the manner of reporting the human performance data. Accordingly, DI-H-1334A has been issued to specify the manner in which human factors engineering testing shall be conducted and reported.

Basically, the test methodology contained in DI-H-1334A works by identifying four factors (the man, his training, what he has to do, and the configuration of the equipment on which he works) and then assessing their compatibility. In addition to that assessment, data are also provided that can be used to (1) verify that the human performance tasks required in the system can, in fact, be performed by humans, (2) accurately identify the aptitudes and skills required by system personnel, (3) establish the adequacy of the proposed training program, and (4) confirm that the materiel itself is adequately human-engineered. The requirements of DI-H-1334A are accomplished by analyzing operator performance requirements, followed by the acquisition of performance data, along with observations of potentially adverse factors such as human errors, equipment incompatibilities, intereference by other operators, and safety hazards.

Since 1972, when DI-H-1334A was approved, a series of events has considerably expanded the potential usefulness of the data item:

1. System Reliability Predictions: In the search for specific management techniques which, when employed, are likely to insure greater system effectiveness, the so-called "system reliability program" has received prominent attention from military managers. Most of these programs attempt to calculate a decimal number representing the probability that a given system (component) will do what it is supposed to do for a stated period of time in a given environment. These probabilities, in turn, are theoretically sensitive to design changes and can thus provide useful information, both in the evaluation of competing concepts and in the assessment of an evolving concept. Certain such reliability estimates have been surprisingly correct; others have not, and their acceptance has resulted in serious engineering errors. When reliability predictions fail, it is often not so much a function of system complexity as the amount of human performance involved. A reliability program which ignores the human component has a high likelihood of providing the potential user with an inflated prediction of system effectiveness, particularly where a "system" can perform its function(s) only if the operator(s) perform critical tasks accurately and promptly. Recognition of this fact is today far more widespread than a decade ago, when an Aerospace Industries Association publication dared to claim, "...equipment reliability in and of itself, without considering the personnel aspect, is only 50% of the reliability picture" (32). In order to make system reliability predictions more accurate, data are required to show the performance reliability of the human operators executing the tasks assigned to them in the system. A modest program was undertaken by the U.S. Army Human Engineering Laboratory in 1972 to show how such data could be gathered and integrated into complex mathematical system reliability models. One of the findings of this program was that DI-H-1334A could be used to collect the needed data (37).

2. Logistics Support and Analysis: As some Army programs strived to increase the quality of performance of systems under development, other programs were trying to reduce the maintenance burden of such new systems. In particular, the Integrated Logistics Support (ILS) program and, more recently, the Logistics Support Analysis Record (LSAR) were instituted to assure that maintenance concerns would be considered adequately during system design and evaluation. The intent of these programs is to identify accurately the personnel skills which would be needed within the maintenance organizations

supporting the new system, to minimize the personnel required to perform the maintenance, and to insure that those personnel with the necessary skills would, in fact, be available in the maintenance support units. None of these determinations can be made accurately without knowledge of what maintenance tasks are to be performed and how well the maintenance personnel can be expected to perform those tasks. Data Item DI-H-1334A is ideally suited as a mechanism to identify and assess these maintenance tasks during the early stages of system design. Indeed, the data generated under the guidance of DI-H-1334A can provide the HFE data needed in the Logistics Support Analysis Record.

3. Training: Within the environment of a volunteer Army, it is extremely important to minimize the amount of time an individual spends in operator or maintainer training, and to maximize the amount of time that individual spends in the unit actually operating and maintaining equipment. In addition, the weapon systems of the modern Army are becoming increasingly sophisticated, requiring highly skilled operators. These two considerations place a heavy responsibility upon system proponents and developers to assess adequately and early the training requirements imposed by a new system. Recent program introductions, including the Skill Performance Aids (SPA)* and the Cost and Training Effectiveness Analysis (CTEA) clearly point to the recognized need to assess the effectiveness and adequacy of training early in system development. Both programs stress the concepts of (1) analyzing the total weapon system and the training subsystem, (2) emphasizing quantitative assessment of measures of effectiveness that are meaningful to decision makers, and (3) performance-oriented training. The key element of both programs is assessment of operator and maintainer performance which has been identified through an adequate task analysis. Additionally, the U.S. Army Human Engineering Laboratory has recently concluded the first phase of a program, entitled "Low-Cost Ownership" (46), to examine a new training concept which appears to have a significant potential for reducing formal training time without adversely affecting the quality of the individual's performance. At the core of this new concept is an early knowledge of the detailed human performance requirements for operations and maintenance. Data Item DI-H-1334A specifically requires (1) that the tasks for each individual operating or maintaining the system be identified, (2) that the performance of these tasks be measured quantitatively, and (3) that the test participant's training be assessed. Thus, DI-H-1334A can provide much of the information needed by SPA and CTEA to assess training effectiveness.

4. Test and Evaluation: In the process of implementing the Life Cycle System Management Model (57), the Army has promulgated several regulations specifying the manner in which test and evaluation shall be conducted. The new Army regulation on testing, AR 70-10, encourages the simultaneous conduct of developmental tests (DT) and operational tests (OT), and makes it clear that contractor facilities may be used for both developmental and operational tests (76). Army pamphlet 602-1 (62), as well as Army regulation AR 70-10, clearly authorizes the U.S. Army Materiel Development and Readiness Command (DARCOM) to measure system performance in DT with soldiers, thus testing the system under conditions similar to OT (i.e., in the hands of user troops). Another recent Army policy, Single Integrated Development Test Cycle Policy

*formerly "Integrated Technical Documentation and Training (ITDT)

(SIDTC), states that developmental testing shall be structured as an integrated test cycle to assure that the contractor, developer, tester, and evaluator interact to minimize test cost and to maximize the use of test data (56). The intent of these regulations and policies is to integrate as much testing as possible and to avoid duplication of tests. At least as far as developmental testing is concerned, this intent also extends to using contractor-generated data, where possible. Inherent in these regulations and policies is the notion that successful development decision making lies in independent evaluation of valid data, rather than the independent conduct of tests.

In keeping with the intent of the new regulations, the Army agencies responsible for test and evaluation are specifying the procedures to be used in evaluating the human factors engineering (HFE) of a system in development. The Test and Evaluation Command (TECOM) has published the Human Factors Engineering Data Guide for Evaluation (HEDGE) (52) and the Operational Test and the Evaluation Agency (OTEA) is sponsoring the development of the Human Resources Test and Evaluation System (HRTES) (17). In both cases, the test and evaluation procedures rest on identifying the activities to be performed by the operators and maintainers. Data Item DI-H-1334A provides a mechanism for a contractor to obtain and report human performance data in a form which can be used by the developmental tester and the operational tester to evaluate the impact of operator and maintainer performance on system performance.

Purpose

It has been the experience of the human factors community, on both sides of the procurement fence, that requirements for human factors analyses, tests, and data are among the first to be waived or neglected in actual development contracts. At the root of this problem is a lack of understanding, on the part of many engineers, managers, and monitors, of both the purposes and procedures associated with HFE data. They may know *what* data are called for, but they do not know *how* to obtain these data and, even more important, they do not know *how* the data should be used. The overall purpose of this report is to provide system engineers, managers, and monitors with descriptions of how to plan and administer HFE testing and how to collect, analyze and interpret HFE test data.

The specific objectives of this report are to: (1) describe how to conduct and report an HFE test according to the requirements of DI-H-1334A, (2) detail the expenditures in time and money associated with the conduct of an HFE test, (3) provide examples of HFE test reports for systems in "experimental prototype" and "advanced development" phases of development, (4) describe the uses of the obtained HFE test data as a function of system development, and (5) explain the impact of the DI-H-1334A findings on a materiel development program.

This document is written for government contract monitors, contract project directors, and contractor HFE personnel. The guidelines for conducting and reporting on the HFE test are intended for experienced HFE personnel (degree in experimental psychology or human factors, or background

in human factors, statistics, and test and evaluation). Therefore, detailed descriptions of the recommended testing techniques are not provided. Instead, techniques are discussed briefly and extensive references are made to the literature on human factors test and evaluation methodology.

Questions of what data are to be collected, how they are to be collected, and how the data can be used are discussed in Chapters 2, 3, and 4 of this report. Chapter 2 is a guide for planning, conducting, analyzing, and reporting on an HFE evaluation according to the requirements of DI-H-1334A. Procedures for managing the HFE evaluation, allocating test personnel, developing test cost estimates, etc., are also contained in Chapter 2. This information will aid project managers in the administration and organization of an HFE evaluation. Chapter 2 will also help the contract monitor supervise the HFE evaluation. The explanations of the DI-H-1334A requirements will assist the contract monitor to understand and monitor HFE tests and insure that all of the requirements of DI-H-1334A are satisfied.

Chapters 3 and 4 supplement the guidelines given in Chapter 2 by giving detailed examples of HFE reports, written according to the requirements of DI-H-1334A. Chapter 3 presents the HFE test report of a system in the experimental prototype stage of development. This sample HFE report focuses on determining the feasibility of human performance, the appropriateness of the tasks allocated to the operator and to the machine, and the adequacy of the workspace layout. This report also demonstrates procedures for conducting HFE tests on mock-up equipment.

Chapter 4 contains the HFE test report of an advanced development prototype. The emphasis in this stage of development is on determining the capability of the operator to perform his assigned tasks within his prescribed time and error standards. This test report also evaluates the adequacy of operator selection and training, as well as the equipment configuration.

Chapter 5 discusses implications of human performance tests. The uses to which data can be applied and the problem associated with conducting HFE tests are also described. By describing how HFE test data can be applied and the benefits of collecting the data, program managers can better appreciate the need for HFE testing.

Approach

Sample Materiel Development Programs. Two HFE tests were conducted to provide samples of procedures for planning, conducting, analyzing, and interpreting HFE test results at different stages of system development. The sample materiel development programs were (1) the mission control station of Compass COPE, and (2) the Communication Control Unit (CCU) of TACFIRE.

Compass COPE is a system of multiple, remotely-piloted vehicles (RPV's) with a mission of high altitude, long duration, long range data acquisition. Up to five vehicles are to be remotely controlled simultaneously from a single mission control station. Compasss COPE is in the "experimental

prototype" stage of development. For the purpose of the HFE test, a static mock-up of the pilot's and copilot's console was constructed (Figure 1).

The CCU of TACFIRE is designed to control digital and voice communication traffic associated with a computerized military operations center. Figure 2 shows the CCU installed in the TACFIRE Fire Direction Center Shelter. Although the CCU is currently in the Low Rate Initial Production phase of materiel development, for the purposes of this report, it was assumed to have just completed advanced development (57).

Sample Program Selection Criteria. Modern materiel systems depend to an ever-increasing extent on built-in data processing capability. Systems such as TACFIRE, TOS, REMBASS, and others already fall into this class; many systems for vehicle and weapons guidance, communications, intelligence, and equipment maintenance are being converted to a computer-based configuration. In such systems, the operator's role is primarily that of an information processor and system effectiveness depends on his ability to obtain, understand, and transmit information. In addition, system operators must frequently interact with software as well as hardware components. The development projects evaluated in this report are representative of these modern materiel systems.

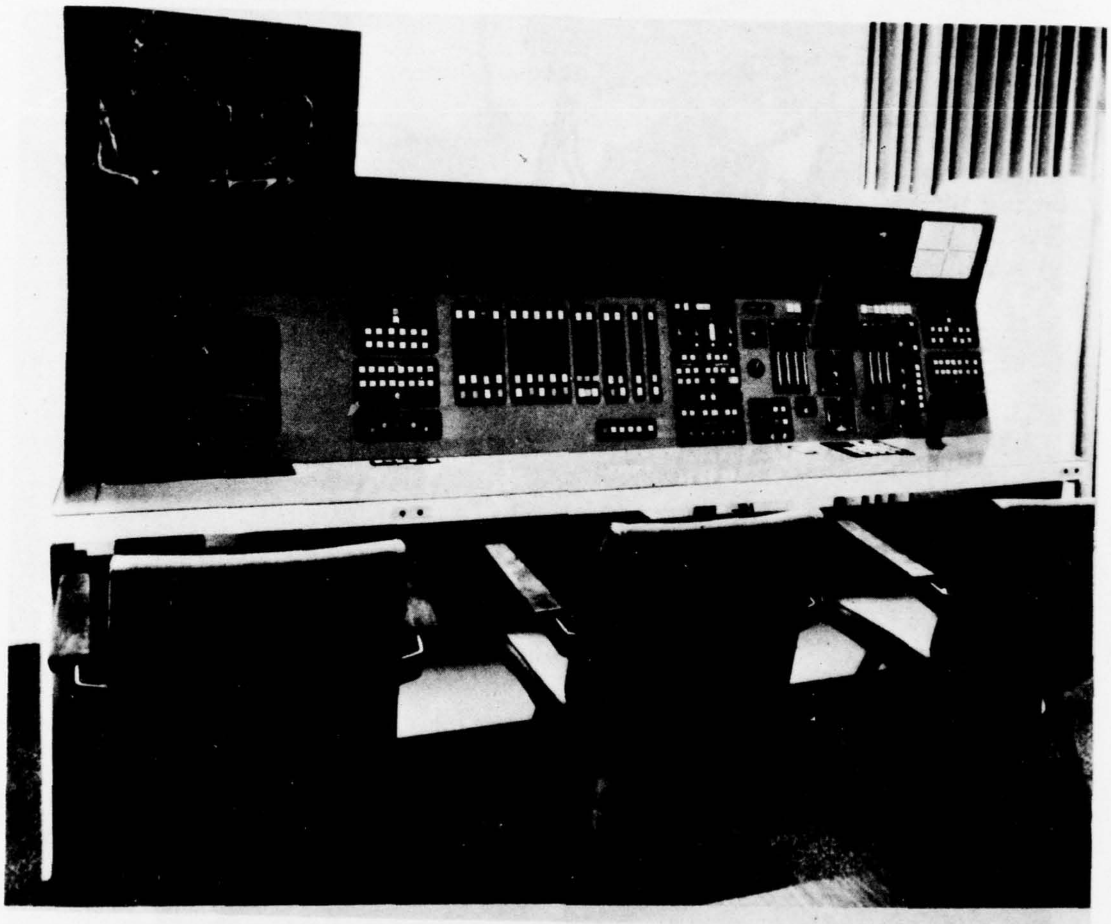

Figure 1. Static mock-up of the Ground Control Station (GCS)

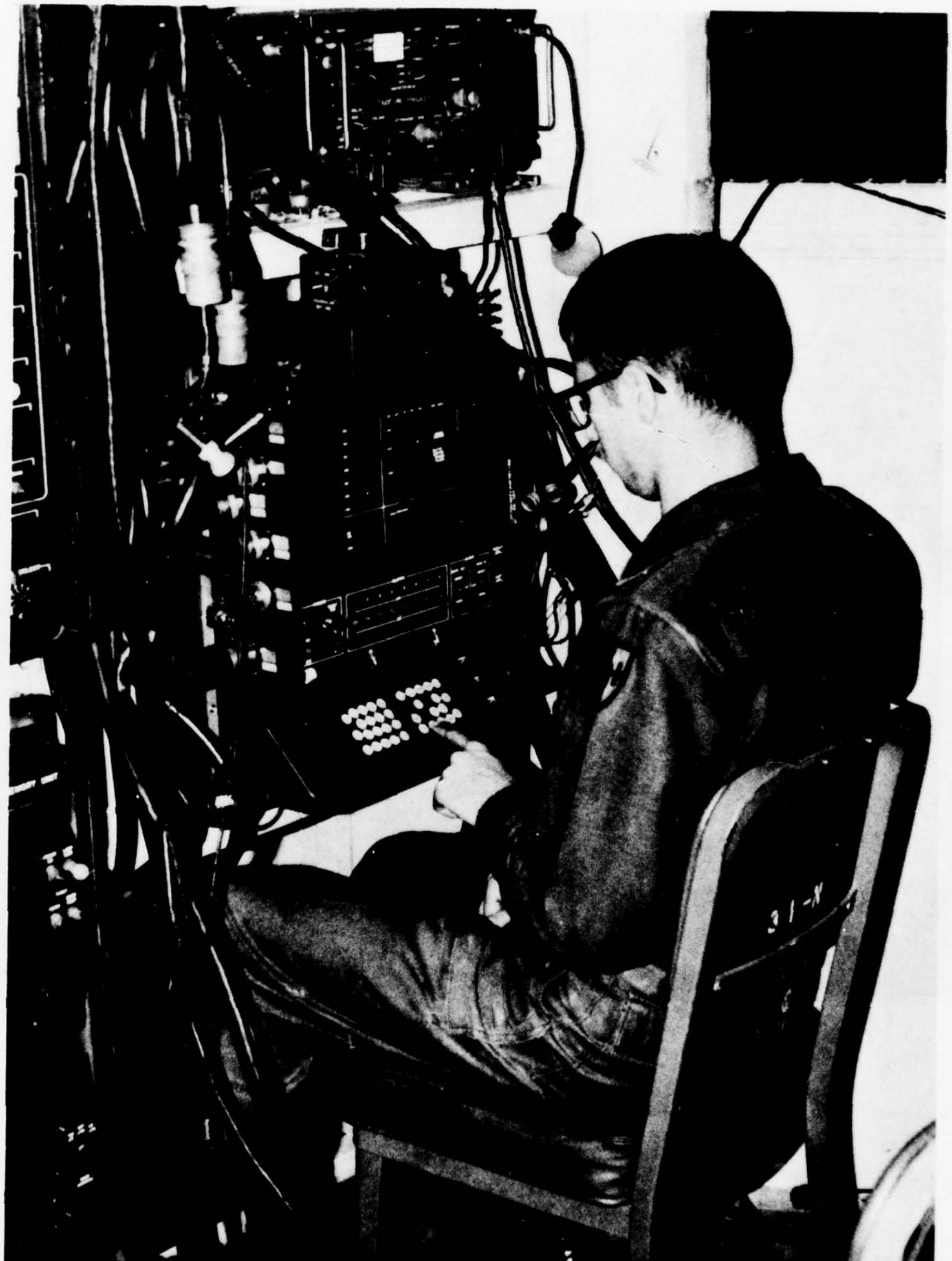

Figure 2. Communication Control Unit (CCU)

GUIDE TO DATA ITEM DI-H-1334A

The checklist shown in Table 1 is a guide for performing an HFE test according to the requirements imposed by DI-H-1334A. This checklist contains all the activities required by DI-H-1334A; thus, the checklist serves as a handy reference for developing HFE test plans, conducting tests, and preparing HFE test reports. Data item DI-H-1334A is shown in Table 2. Block 10 of the data item lists specific requirements for the HFE tests and reports.

Each section of this chapter is labeled in accordance with Table 1 and gives detailed explanations of the activities specified in the test checklist. Frequent references are made to the two test reports contained in chapters 3 and 4. These two sample reports illustrate methods for accomplishing the required test activities for projects in the experimental prototype and advanced development prototype phases of materiel development. Throughout the discussions of the HFE test activities, extensive references to the human factors literature are made to provide further descriptions of test procedures.

Test Administration

While methods for managing human factors tests vary as a function of the contractor's organization, a single person should normally be appointed to manage all of the activities described in this chapter. A useful guide for managing projects is provided by Abramson and Kennedy (1).

The first task of the test manager will be to review the test requirements described in this chapter and block 10 of the data item. With a comprehensive view of the test requirements, the manager can develop the preliminary test milestones, specify the personnel requirements, and prepare the test budget.

Milestone Development. The test manager should develop test milestones to provide a guideline for timely execution of test activities and for scheduling test personnel, equipment, and facilities. A milestone is an activity with a definable end point or product. Test activities of the HFE checklist shown in Table 1 identify the test milestones to be completed in a HFE test. Table 3 shows the milestone chart for the HFE test of the TACFIRE CCU (Sample of Advanced Development Prototype). As shown in Table 3, test administration activities continue throughout the test program.

Manpower Specification. Manning requirements for a DI-H-1334A test depend upon the number of personnel positions in the system and the complexity of the tasks being evaluated. The greater the number of system personnel and the more complex their performance requirements, the greater the amount of manpower required to conduct the test. A test manager is required to oversee the tests and to insure that all required data are properly collected. In addition to the test manager, one test person is generally required for each personnel position being evaluated, depending

TABLE 1

HFE Test Checklist

TEST ACTIVITIES	SOURCE OF INFORMATION
1. TEST ADMINISTRATION	
1.1 Milestone Development	1334A, HEL TM 29-76, System test milestones
1.2 Manpower Specification	Available organization personnel
1.3 Budget Preparation	Manpower needs, Organization budget procedures
2. TASK GROUP DESCRIPTION	
2.1 Task Group Identification	MOS or Analysis of personnel position
2.2 Task Analysis	Equipment configuration, Task allocation
2.3 Performance Standards Identification	System performance specifications
3. TEST PLANNING AND DESIGN	
3.1 Test Objectives Specification	1334A, Previous HFE tests, System contract, Stage of development
3.2 Test Equipment Design and Selection	System description, TASA, Stage of development
3.3 Test Environment Measurement	Analysis of operational environment, Stage of development
3.4 Test Participant Selection	Task group identification, Expected test variability, Stage of development
3.5 Test Participant Training	Participants' experience, System development stage
3.6 Data Acquisition and Analysis Planning	System development stage, Statistics literature
3.7 Test Segment Development	TASA, Stage of development, Preliminary hazard analysis
3.8 Test Schedule Preparation	Test segments, Number of test personnel
3.9 Test Dry Run Execution	Test plan, Test segments
4. HFE TEST EXECUTION DATA ACQUISITION	
4.1 Pretest Procedures	Prepared questionnaires, Training materials
4.2 Test Execution	Objective performance measures, Test plan
5. DATA ANALYSIS	
5.1 Objective and Subjective Data Summarization	Performance measures
5.2 Problem and Error Description	Data records
5.3 Man-Machine Incompatibilities	Data records, Observations of test personnel
5.4 Human Performance Impact Assessment	Performance standards or baseline task as comparison
6. REPORT PREPARATION	1334A, Test plan, Analyzed data

TABLE 2

Data Item DI-H-1334A

DATA ITEM DESCRIPTION	2. IDENTIFICATION NO(S).	
	AGENCY	NUMBER
1. TITLE Report(s) of Human Factors Engineering Test	Army	DI-H-1334A
3. DESCRIPTION/PURPOSE Used to determine whether and to what level or standard(s) each trained individual can perform in the specified sequence all of the performance tasks assigned to him in a system;[1] to determine whether and to what extent his performance is affected by equipment configuration, the performance of other system personnel, or both; and to assess the impact of the measured human performance on the attainment of system performance goals.	4. APPROVAL DATE 1 October 1976 5. OFFICE OF PRIMARY RESPONSIBILITY DRXHE-PC 6. DDC REQUIRED 8. APPROVAL LIMITATION	
7. APPLICATION/INTERRELATIONSHIP Serves as the principal means of substantiating the feasibility of required human performance, the accuracy of the personnel selection criteria, the adequacy of the training program, and the acceptability of the man-machine interfaces. When DI-H-1313 (HFE Test Plan) is also a contractual requirement, it shall include a section which describes in detail the efforts necessary to accomplish the test described below. This DID supersedes DI-H-1334.	9. REFERENCES (Mandatory as cited in block 10) AR 70-10 AR 602-1 MIL-H-46855 MIL-STD-1472 MIL-STD-1474 MIL-HDBK-759 HEL TM 29-76 MCSL NUMBER(S)	

10. PREPARATION INSTRUCTIONS

The Report(s) of HFE Test shall be submitted by the contractor to the procuring activity for each personnel position in the system being developed.[2] All of the operations and maintenance tasks required of the soldier assigned to a personnel position are referred to as the "task group" of that position. This data item may be submitted incrementally to facilitate use of test results (i.e., portions of a task group, or only one task group, may be tested and reported separately). However, this data item shall not be considered complete and acceptable until all task groups in the system and the interactions of each have been tested and reported. The Report(s) of HFE Test shall include, but not necessarily be limited to, sections described by the following paragraphs and notes:

1. INTRODUCTION

a. Identification of task groups (or portions thereof) reported.

b. For each task group or portion thereof reported, a brief summary of major tasks (including interactions with other operators and maintainers) and a brief description of the physical area in which they are to be performed when the system is fielded.

c. Date(s), location(s) and names(s) of individual(s) present and supervising conduct of the HFE test.

2. TEST PREPARATION

a. Statement of the task groups (or portions thereof) being reported. (A list, in

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2. TEST PREPARATION (continued)

sequential order, of all the discrete performance tasks which will be required of each person in the system.

b. Statement of (or reference to) any human performance standards (e.g., ".9 probability of gunner launching missile within 10 seconds after detecting target") or assumed contribution to error (e.g., "aiming error less than 3 mils") contained in system development documents. If none, so state.

c. Description of environment at each distinct location of human performance. (Include noise and illumination levels, shock and vibration, air temperature and humidity, and ventilation. Also state the concentration and exposure time of test participants to any toxic or hazardous substances; and state whether that exposure was or was not within the applicable safety limits for each substance.)

d. Description of test participants.[3] For each participant, state age, weight, body dimensions relevant to performance tasks (see paragraphs 3.1 and 5.6, MIL-STD-1472), visual acuity and hearing levels, any known physical disabilities, and score from a standardized measure of general intelligence.

e. Description of individual clothing and equipment (including all clothing and equipment worn, carried or otherwise borne on the body such as weapon, communications equipment, headgear and protective mask[4]).

f. Type and amount (in hours) of system-specific pre-test training (differentiating "hands on" practice from other training) given to test participants; and type, content and results of training assessment[5] used. Also state time intervals between end of training, training assessment, and start of HFE tests being reported.

g. Description of mockup or equipment on which HFE test is conducted (including material used and type of fabrication; dimensions; and cross-reference to blueprints, drawings or sketches).

h. Identification of deviation(s) during the HFE test from conditions of expected use (paragraph 1.b. above); narrative explanation of reason(s) for deviation(s), and presumed effect of such deviation(s) on the validity of generalizations from test data.

3. DATA COLLECTION TECHNIQUES

a. Identification of the quantitative and qualitative measures of both human and system performance.

b. Description of methods, procedures and instrumentation used in data collection.

c. Description of techniques used for data reduction, statistical techniques employed, and confidence levels selected.

(Continued)

4. HFE TEST RESULTS

a. Summaries of quantitative human and system performance data.

b. Summaries of qualitative data (including questionnaires, interviews, checklists, etc.).

5. DESCRIPTION OF HUMAN PERFORMANCE ERRORS

a. Narrative description, with photograph(s) if appropriate, of each error. Include frequency of occurrence of each error during test.

b. Consequence (brief statement of the immediate effect of the error on system operation).

c. Causes (isolation of the immediate cause of each actual performance error and identification of the events, conditions, operator workload, environmental factors and equipment configurations which may have contributed to it).

d. Explanation of participants making errors and the reasons for the errors.

e. Recommended solutions (stated in terms of equipment redesign, alteration of tasks, personnel selection and/or training). Provide rationale.

6. DESCRIPTION OF INCOMPATIBILITIES AMONG HUMAN PERFORMANCE AND EQUIPMENT

a. Identification

(1) During the test what tasks of one task group interfered with the performance of which tasks of another task group? If none, so state.

(2) During the test what two or more items of equipment were found to be incompatible and what human performance was affected? If none, so state.

(3) During the test what human performance was adversely affected by what equipment configurations or characteristics? (Identify controls and/or displays needed but not present.) If none, so state.

b. Recommended solutions (stated in terms of equipment redesign, alteration of tasks, personnel selection and/or training). Provide rationale.

7. DESCRIPTION OF OBSERVED SAFETY HAZARDS

a. Narrative description, with photograph(s) if appropriate, of each safety hazard identified during the test.

b. Frequency each hazard was encountered by test participants.

c. Severity and consequence of each hazard.

(Continued)

7. DESCRIPTION OF OBSERVED SAFETY HAZARDS (continued)

d. Recommended action to eliminate or minimize hazard (stated in terms of equipment redesign, alteration of tasks, personnel selection and/or training). Provide rationale.

8. ANALYSIS OF IMPACT OF HUMAN PERFORMANCE ON ATTAINMENT OF SYSTEM PERFORMANCE GOALS

a. Statement of (or reference to) system performance goals.

b. Narrative explanation of reasons why any human performance tasks required by present equipment design are not feasible; or why any standards presently set for specific human performance tasks are unattainable. (If all human performance requirements are feasible and any standards set appear to have been met, so state.)

c. Narrative explanation of how measured human performance errors in operations and maintenance can affect reliability and availability.

d. Narrative explanation of how measured human performance times and error frequencies and magnitudes can affect system effectiveness.

e. Narrative explanation of how system performance goals would be affected by implementing the solutions recommended in subparagraphs 5.e., 6.b. and 7.d (above).

9. CONCLUSIONS

a. Summary of major test findings.

b. Summary of implications for system performance (reliability, availability and effectiveness) of the human performance measured in this test.

c. List of recommended changes to equipment configuration, human performance tasks, personnel selection and/or training (in order of decreasing importance).

NOTES

1. "System" is defined as a composite of hardware (and any software), the personnel who operate and maintain it, the training they receive, and the tools and reference publications they use.

2. A task group is "in the system" if a soldier must perform tasks on equipment produced by the contractor or a subcontractor (e.g., a squad leader would not be "in" a new machinegun system even though he supervised the machinegunner; but the assistant gunner and the unit maintenance technician would be).

3. Performance data from at least three different individuals are required for each task tested.

(Continued)

NOTES (Continued)

4. Unless otherwise stated in Block 16 of that sequence on DD Form 1423 which makes this data item a contractual requirement, performance data (reported in paragraph 4 above) shall be gathered while test participants carry the protective mask in an approved manner on the body; but do not wear it.

5. Each test participant shall be tested to determine his or her comprehension of task group performance requirements prior to the gathering of the data reported in paragraph 4 above. The purpose of this test is limited to verifying that each test participant knew what he or she was supposed to do with the equipment before data gathering began; this requirement is not primarily intended to be an assessment of the New Equipment Training (NET) Program.

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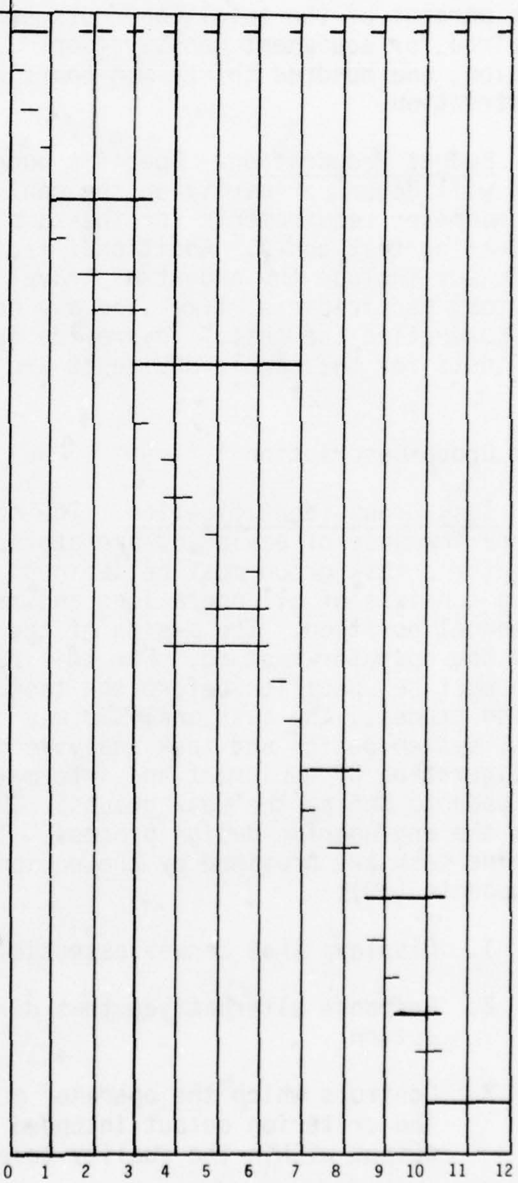
(Concluded)

TABLE 3

Sample Test Milestone Chart

TEST ACTIVITIES

1. TEST ADMINISTRATION
   - 1.1 Milestones Development
   - 1.2 Manpower Specification
   - 1.3 Budget Preparation
2. TASK GROUP DESCRIPTION
   - 2.1 Task Group Identification
   - 2.2 Task Analysis
   - 2.3 Performance Standards Identification
3. TEST PLANNING AND DESIGN
   - 3.1 Test Objectives Specification
   - 3.2 Test Equipment Design and Selection
   - 3.3 Test Environment Measurement
   - 3.4 Test Participant Selection
   - 3.5 Test Participant Training
   - 3.6 Data Acquisition and Analysis Planning
   - 3.7 Test Segment Development
   - 3.8 Test Schedule Preparation
   - 3.9 Test Dry Run Execution
4. HFE TEST EXECUTION
   - 4.1 Pretest Procedures
   - 4.2 Test Execution
5. DATA ANALYSIS
   - 5.1 Objective and Subjective Data Summarization
   - 5.2 Problem and Error Description
   - 5.3 Man-Machine Incompatibilities
   - 5.4 Human Performance Impact Assessment
6. REPORT PREPARATION



upon the method of data collection. This test person is responsible for monitoring test participant performance and for recording test data.

To provide a yardstick for estimating test manpower requirements, the number of man-hours required to complete the two sample HFE tests is shown in Table 4. A substantial proportion of the time spent in conducting an HFE test will be spent in planning. Efficient planning will facilitate data acquisition and analysis and will contribute to cost reduction. Test planning was a major effort of the sample tests and consumed about thirty-four percent of the total man-hours expended. Additional man-hours may be required for equipment construction. In the HFE test of the RPV control station, one hundred thirty man-hours were required for mock-up design and construction.

Budget Preparation. Specific budget requirements for the human factors test will depend primarily on the contractor's in-house budget procedures. The manpower requirements for the sample HFE tests provide a basis for estimating test costs. Additional factors which may influence the budget estimates include the amount of travel to and from the test site, any payment for test participants' time, and any equipment required for a mock-up and for conducting the test. To provide guidance in preparing test budgets, the costs for the sample HFE tests are shown in Table 5.

Task Group Description

Task Group Identification. The objective of the HFE test is to evaluate the performance of equipment operators. To perform the evaluation, the operator's task group must be defined. As defined by DI-H-1334A, a task group consists of all operations and maintenance tasks assigned to a single personnel position. The design of the machine and its intended use determines what the operator must do. For this reason, the general equipment configuration must be specified before the task analysis is completed. In the actual design process, the task analysis may identify needed design revisions. Thus, system design and task analysis is an iterative process. The configuration of equipment and information obtained from the task analyses are used to define the task groups. The equipment configuration is obtained from the engineering design process. The behavioral requirements of a man-machine task are provided by the equipment in the form of the following components (39):

1. Displays that convey essential information to the operator

2. Response alternatives that direct the operator to select a course of action

3. Controls which the operator must activate certain ways to produce the criterion output intended for the machine produces its criterion output within the quality tolerances specified.

Task Analysis. A task analysis defines, systematically and in as much detail as necessary, the behavioral requirements of the tasks to be accomplished. It describes the kinds of discriminations that must be made, the

TABLE 4

Man-Hour Requirements for Sample HFE Tests

TEST PHASE	HFE TEST EXPERIMENTAL PROTOTYPE (RPV Controllers)	ENGINEERING DEVELOPMENT PROTOTYPE (CCU Operator)
Administration	70	60
Task Group Description	160	130
Test Planning and Design	180	210
Test Execution	100	100
Data Analysis	120	80
Report Preparation	130	140
TOTAL	760	720

TABLE 5

Sample HFE Test Budgets

COST CATEGORY		HFE TEST: EXPERIMENTAL PROTOTYPE (RPV Controllers)	HFE TEST: ENGINEERING DEVELOPMENT PROTOTYPE (CCU Operator)
Labor[a]		$ 9,490.00	$ 8,300.00
Mock-up		4,000.00	-
Plan	$ 900.00		
Design	1,460.00		
Materials	440.00		
Fabrication	1,200.00		
Test Participants[b] (50 hrs. @ $31/hr.)		1,550.00	-
Test Material & Equipment[c]		150.00	150.00
Travel		600.00	1,800.00
Consultant[d]		-	1,650.00
G & A		2,680.00	2,020.00
Fee/Profit		1,475.00	1,110.00
TOTAL		$19,945.00	$15,030.00

[a]Burdened labor rate including direct labor and overhead.

[b]Military personnel were used as test participants in the CCU test. No fee charged for their services.

[c]Does not include HFE instrumentation equipment which was available for use in these tests.

[d]Consultant provided background information on CCU. Similar support from Teledyne Ryan Aeronautical was provided at no cost.

decision making requirements, and the motor responses to be made by the operator. In the present case, the task analysis is used to identify the task group performance requirements to be evaluated in the HFE test.

Task definitions have been widely discussed in the human factors literature (8, 33, 39). To summarize these definitions, a task may be defined as a stimulus-response relationship. The stimulus is sensed by the operator, is interpreted by him, and elicits a response. The completion of the task must satisfy a specific requirement and it must involve the output of only one man in some combination with machine components. Above all, a task must be goal directed. That is, a task is a series of actions leading to a meaningful outcome.

The manner in which tasks are described depends on the task taxonomy selected and the stage of system development. Many task taxonomies have been developed (6, 11, 39), varying primarily in the level of detail of the analysis. However, no universal taxonomy is dominant since the required level of detail depends on the purpose of the task analysis. For the purposes of the HFE test, the simple taxonomy shown in Table 6 is recommended. In general, the taxonomy should conform to the level of detail found in the stage of equipment development. For systems in the experimental prototype phase of development, a two-level taxonomy (i.e., task and subtasks) should be sufficient. For example, a two-level taxonomy corresponded to the level of detail in the experimental prototype (RPV station) test. For the advanced development prototype (CCU) test, a three-level taxonomy (i.e., task, subtask, and task element) was used to describe the operators' actions.

Although there are differences in emphasis and types of formats used, all task analyses should include the following steps:

1. Determine system functions

2. Trace each function to the machine output or to a control

3. Determine display information necessary for operator to decide to activate a control or monitor a system state

4. Determine feedback given by machine to indicate appropriate operator response

5. Insure that each stimulus is linked to a response and each response to a stimulus.

Many different formats have been developed for recording and presenting task analysis data. Some of the more widely used techniques are:

1. Task and Equipment Analysis (TEA)

2. Operational Sequence Diagrams (OSD)

3. Combined TEA and OSD

4. Task Demands Analysis.

TABLE 6

Sample Task Taxonomy

FUNCTION	
	Activities assigned to person on machine or between person and machine (e.g., vehicle operation).
*JOB	
	The combination of all human performance requirements (duties and tasks) or one personnel position in a system (e.g., pilot, driver, gunner).
DUTY	
	A set of operationally related tasks within a given job (e.g., control aircraft, drive truck, manage/operate system).
*TASK	
	A composite of related activities (perceptions, decisions, and responses) performed for an immediate purpose; written in operator language (e.g., takeoff from airfield, prepare for departure, load gun).
SUBTASK	
	Activities (perceptions, decisions and responses) which fulfill a portion of the immediate purpose within a task (e.g., monitor engine instruments, assess passenger safety, position ammunition).
TASK ELEMENT	
	The smallest logically definable unit of behavior required for completing a task or subtask (e.g., verify RPM between 4500-6000, verify seat belts being used, insert belt into feeder).

*Required

Several authors have documented the procedures for performing these task analyses (2, 11, 20, 21, 28, 31). However, few specific guidelines are available on what task analysis technique to use. In general, use the technique you are most fámiliar with and perform the analysis to the level of detail possible considering the stage of system development. The TEA and OSD techniques provide methods for identifying tasks which must be performed simultaneously by several operators. This is particularly true for these techniques when they include a time-line analysis. These techniques can also be used to identify potential interference between two or more task groups.

As illustrated in the two sample HFE tests, Task and Equipment Analyses were used to derive the sequential lists of operator tasks. These lists of tasks provided the basis for generating (1) the test scenarios which defined the test participants' tasks and (2) the behavioral checklists used to evaluate their performance.

Performance Standards Identification. A man-machine system is an organization whose components are men and machines, working together to achieve a common goal (19). In the context of the Life Cycle System Management Model, and particularly with regard to the HFE test, the 'system' "...consists of hardware (and sometimes software); personnel who operate, maintain, and support it; the training they receive; and the tools, manuals, and equipment they use" (58). System requirements delineate what the system must be able to do: its objectives. Requirements include the mission or purpose of the system and the levels and kinds of performance needed to meet system goals.

The purpose of analyzing these requirements is to identify the specific functions the system must perform. Functions are the most general, yet differentiable means whereby the system requirements are met, discharged, or satisfied (8). Identification of functions leads to a determination of the types of human and equipment capabilities required to satisfy system requirements. From a human engineering standpoint, analyzing system requirements includes identifying the personnel tasks, the specific task performance standards, and the personnel selection and training requirements.

System requirements are almost always specified by the customer. Requirements are first expressed qualitatively, then quantitatively, and become increasingly more precise as system development proceeds. Specific equipment and personnel performance standards are typically developed after functions have been allocated and specific tasks have been determined. Human performance standards are developed by working backwards from system requirements and determining the maximum allowable task times and error rates acceptable that will still allow the mission to be completed satisfactorily. In the case of systems acquired by the government, new procurement policies (42) indicate that system requirements will be given in terms of required system performance, rather than design specificiations. In keeping with the taxonomy shown in Table 6, the government will thus specify the missions and scenarios (and the associated performance standards), while the contractor will specify the system functions, tasks, etc. (and their associated performance standards).

Several authors specify procedures for developing performance standards (8, 28, 31, 33, 78). In many instances, system requirements are stated in terms of hardware requirements with no statement of human performance influences. HFE tests can be conducted in the absence of performance standards; however, the effect of performance on overall system effectiveness can then be expressed only with regard to assumed standards.

Test Planning and Design

Test Objectives Specification. Test planning begins with a statement of the test objectives. In general, the more precisely the test objectives are defined, the easier it is to develop the test plan. Since testing costs money, the scope of the test should not only consider the objectives of the present test but also what has been determined from previous tests (56). Indeed, the Single Integrated Development Test Cycle policy (SIDTC) clearly specified that tests shall not be duplicative. Thus, it should not be necessary to replicate earlier test findings. For example, if a certain sequence of tasks has already been evaluated, and hardware or procedural changes have not been made during the intervening period, it would be a waste of test time and money to re-evaluate these tasks. Also, feasibility of task performance is generally determined before a system proceeds to advanced development. If task feasibility has been demonstrated in early development testing, further time and money should not be spent re-evaluating feasibility in the later stages of development. Procedures for developing test objectives are given in DI-H-1313A and have been documented in the literature (31, 33).

Test Equipment Design and Selection. The nature of the HFE test equipment configuration depends upon the stage of system development. Specific task group performance questions are answered most cost-effectively at different stages of system development. Control and display arrangement, man-machine function allocation, and accessibility of components for maintenance, etc., are determined most effectively before any prototype hardware is built. Mock-ups should be used to answer these types of questions. For a test of a system in experimental prototype development, a mock-up will often be required. As system development progresses, breadboard and brassboard prototype equipment will be included in the test station.

Specific questions on the ability of the task group to meet or exceed performance specifications are best answered on operational equipment. Sophisticated, dynamic computer-controlled mock-ups and simulators can also be used as test equipment in the later stages of system development. Dynamic mock-ups and simulators should be used only when they are the most cost-effective method of answering questions critical to mission success. For example, simulators are often used in flight training because it is cheaper and safer to train pilots in simulators than it is to train them in aircraft. The literature also contains procedures for developing and evaluating mock-ups (5, 45, 78).

Test Enviroment Measurement. An HFE test must take into account the environmental conditions under which the personnel and equipment are expected to be used. However, to be cost-effective, the HFE test need simulate only

those environmental conditions which are likely to affect task group performance. Objective (previous tests or analysis of relevant performance literature) or subjective (interviews or questionnaires of subject-matter experts) methods should be used to determine the environmental conditions to be simulated and measured. The Materiel Test Procedure (MTP) (63-75) for the class of equipment being tested should be reviewed to determine the critical measurements to be taken. Major environmental measurement areas that should be considered are also shown in Table 7.

The degree to which the test environment simulates operational conditions depends upon the stage of system development. Normally, it is not cost-effective to allocate substantial resources to simulate all expected use conditions during the early stages of development. For example, even if vibration is expected to affect task group performance, little would be gained by simulating vibration when the participants are being tested on a static mock-up since the effects of these environmental conditions should be estimated by analysis and by reference to previous experimental results. Environmental "realism" should be incorporated in tests in the later stages of system development. The effects of environmental conditions on performance are best assessed on dynamic mock-ups, simulators, and on prototype equipment that include all the critical environmental conditions of the field-deployable system.

After the required environmental conditions have been specified for the HFE test, provisions must be made for measuring these critical conditions during the test. If the test environment is stable, the environmental measurements need be recorded only once during the test period. However, changing environmental conditions will necessitate more frequent measurement. Table 8 lists the measurement instruments of the Human Factors Instrumentation Package (61) which can be used to measure the environmental conditions. This HFE Instrumentation Package contains all of the instruments required to obtain the environmental measurements recorded in the two sample HFE tests. To reduce test costs, a contractor may be able to borrow an HFE Instrumentation Package from the human engineering unit at the Army command which issues the system development contract. A comprehensive summary and description of environmental recording techniques and procedures are contained in the reference manual for the Human Factors Instrumentation Package. Environmental measurement techniques are also discussed in the Human Factors Test and Evaluation Manual (24) and in selected Materiel Test Procedures (63, 70, 71, 75).

Test Participant Selection. To a large extent, the validity of the HFE test results depends on how well the human factors engineer is able to match his test participants to the characteristics of the personnel who will ultimately use the equipment. In early stages of system design, participants are usually drawn from contractor technicians, engineers, and other company personnel. Contractor personnel are often more skilled and experienced than the military personnel who will ultimately use the system, and this disparity can sometimes lead to erroneous conclusions. For example, highly skilled personnel may not be aware of difficulties which would be severe if less skilled personnel were using the equipment. However, the advantage of using highly skilled personnel in the early stages of development cannot be ignored.

TABLE 7

Test Measurement Categories

MEASUREMENT AREA	EVALUATION AREA					
	PHYSICAL OPERATING ENVIRONMENT	DISPLAYS AND COMMUNICATION	CONTROLS	WORKSPACE	ACCESS/EGRESS	SAFETY
NOISE	Wide Band Noise (1) Octave Band Analysis (1) Impulse Noise (1)	Articulation Index (1) S/N Ratio (1) Pre-Emphasis Slope (1) Filtering Characteristic (1)		Wide Band Noise (1) Octave Band Analysis (1) Impulse Noise (1) Noise Criterion (1) Reverberation Time (1, 18)		Maximum Noise Level (1)
VIBRATION AND SHOCK	1/3 Octave Vibration Analysis (2) Peak Shock (1 and 2)	1/3 Octave Vibration Analysis	1/3 Octave Vibration Analysis (2)	1/3 Octave Vibration Analysis (2) Peak Shock (1 and 2)		Whole Body Safety Limits(2)
VISIBILITY	Illumination Level (3) Glare (3)	Luminance Level (3 or 4) Illumination Level (3) Contrast Ratio (4) Background Brightness (4)	Luminance Level (3) Contrast (4)	Illumination Level (3) Glare (3) Surround Brightness (3,4)	Illumination Level (3)	
THERMAL AND ATMOSPHERIC ENVIRONMENT	Air Temperature (6 or 9) Humidity (6 or 8) Air flow (7) Wind Speed and Direction(6) Air Pressure (6)		Surface Temperature (9)	Air Temperature (9) Humidity (6 or 8) Air Flow (7) Temperature Uniformity (9)		Surface Temperature (9) Air Temperature (9) Exposure Limits (6, 7)
NOXIOUS GASES	CO_2 Level (10 or 11) CO Level (10 or 11) NO_2 Level (10 or 11) SO_2 Level (10 or 11) Other Gases (11)			CO_2 Level (10 or 11) CO Level (10 or 11) NO_2 Level (10 or 11) SO_2 Level (10 or 11) Other Gases (11)		Toxic Hazards (10, 11)
FORCE AND DIMENSION	Angle of Incline (5)	Display Height, Size and Angle (5) Range of Motion and Angle(5)	Control Force (5) Control Torque (5) Clearance (5) Control-Display Ratio (5)	Lifting Force (5) Lifting Height (5) Seat and Work Surface Dimensions (5) Angle of Incline (5)	Clearance (5) Handle Force (5)	Lift Limits (5) Clearance (5)
ANTHROPOMETRY		Field of View (12)	Operator Hand, Arm, Leg, Foot, and Torso Sizing for Population Extremes (12)	Operator Sizing for Population Extremes (12)	Operator Sizing for Population Extremes(12)	
PERFORMANCE	Effect of Extreme Environment on Performance (13, 14,16)	Missed Signals (14) Frequency of Use (13,14,16) Observer Comments (17) Signal Rate (13) Signal Duration (13)	Inadvertent Operations (14, 16) Frequency of Use (13,14 or 16) Time Lag (13)	Layout Efficiency via Time and Motion (16)	Emergency Exit Time (13) Exit Procedures (16)	Emergency Procedures (16)
PHYSIOLOGICAL	Skin Temperature (9) Core Temperature (9) Subject Comments (17)			Skin Temperature (9) Core Temperature (9) Subject Comments (17)		

NOTE: Table entries are specific measurements.
Numbers in parentheses refer to instrument list (Table 8).

TABLE 8

Measurement Equipment List

MEASUREMENT AREA	INSTRUMENT		COMPONENTS AND/OR ACCESSORIES	MANUFACTURER
NOISE and VIBRATION	1	Sound Level Meter/Analyzer	Microphone, extension cable, AC adaptor/charger, carrying case	General Radio 300 Baker Avenue Concord, Massachusetts 01742
			Tripod	
	2	Vibration Level Meter Analyzer	Vibration pick-up and mount, remote measuring package	
ILLUMINATION and BRIGHTNESS	3	Photometer	Sensor probe, illumination and luminance receptors, carrying case	Photo Research Division Kollmorgen Corporation 3000 North Hollywood Way Burbank, California 91505
	4	Spot Brightness Meter	Close-up lens, battery pack	
FORCE and DIMENSION	5	Force, Torque, and Dimension Kit	Dial torque gauge, dial force gauge	Chatillon 83-30 Kew Gardens Road Kew Gardens, New York 11415
			Push/Pull gauge (3), dial torque wrench (2), torque adaptor, socket set, adj. protractor, tape measures (2)	
ATMOSPHERIC ENVIRONMENT	6	Portable Weather Station	Wind speed and direction, temperature, humidity and barometric pressure meters	Weather Measure Corporation P.O. Box 41257 Sacramento, California 95871
			Wind sensor (vane)	
	7	Hot Wire Anemometer	Remote probe, carrying case	
	8	Aspirating Psychrometer	Psychrometric slide rule	
	9	Digital Thermometer	Instrument with built-in battery pack charger	Digitec, Inc. 918 Woodley Road Dayton, Ohio 45403
			Remote probes (surface, air, oral)	
POLLUTANTS	10	Universal Gas Tester	Detector tubes (CO, CO_2, NO_2, and SO_2), hand pump, remote sampling tube, carrying case	Mine Safety Appliances Co. 400 Penn Central Boulevard Pittsburgh, Pennsylvania15235
	11	Monitoring Gas Sampler	Dust collector, gas impinger, battery pack/charger	
ANTHROPOMETRY	12	Anththropometry Instrument Kit	Anthropometer, tape, sliding caliper, spreading caliper, carrying case, goniometer, weigh scale	Siber Precision, Inc. 450 Barell Avenue Carlstadt, New Jersey 07072
PERFORMANCE	13	Digital Timer	Remote-control switch, clipboard	Heath Company Benton Harbor Michigan 49022
			AC adaptor/charger, carrying case	
	14	Multiple Event Counter	Digital counter (3) Push-button switch (3) Photocell switch (1)	Waugh Controls Corporation 7621 Hayvenhurst Avenue Van Nuys, California 91406
	15	Polaroid SX70 Camera	Close-up lens, flash bar, tripod, carrying case,	Polaroid Corporation 730 Main Street Cambridge, Massachusetts02139
	16	Videotape Recording System	Camera, recorder, monitor, zoom lens AC adaptor/charger, carrying case	Panasonic 200 Park Avenue New York, New York 10017
			Extension cable	
			Tripod	
RECORDING and ANALYSIS	17	Audio Tape Recorder	Remote microphone, AC adaptor/charger, carrying case, earphone	Sony, Inc. 2150 Vineland Avenue Sun Valley, California 91352
	18	Instrumentation Tape Recorder	Microphone, connector cables, battery pack/charger, earphone	Teac Corporation of America 7733 Telegraph Road Montebello, California 90640
			Recorder, carrying case	
	19	Scientific Calculator	AC adaptor/charger soft carrying case, travel case	Hewlett-Packard, Inc. 10900 Wolfe Road Cupertino, California 95014
MAINTENANCE and CALIBRATION	20	Digital Test Meter	Remote probes, AC adaptor/charger, carrying case	Weston Instruments, Inc. 614 Frelinghuysen Avenue Newark, New Jersey 07144
	21	Tool Kit	Assorted screwdrivers, nut drivers and pliers.	Xcelite, Inc. 770 Bank St. Orchard Park, N.Y. 14127
	22	Battery Charger		General Electric Company

Such skilled personnel can provide detailed information on task sequencing and definition. They can also provide information on the adequacy of the control-display layout (For example, are all of the required controls and displays present, and are any unnecessary controls included, etc.?).

Although the practice of using contractor personnel as test subjects is common, simple, and expedient, it almost invariably results in biased outcomes (78). This practice of using overly-skilled personnel should be limited to testing in the earliest stages of development. The importance of using representative personnel as test participants increases as a system nears completion. Geddie (12) provides a good description of the methods and criteria to be used in selecting test participants for developmental tests. The advantages of using military personnel include the following:

1. Military personnel are usually more representative of the user population than are contractor personnel. When selected from intended user organizations, military personnel will be representative in terms of:

    a. Skill level (similar Military Occupation Specialty)

    b. Motivation (no particular incentive to make equipment "look good")

2. Testing costs can be reduced since Single Integrated Development Test Cycle (SIDTC) (56) policy envisions use of government-supplied military test participants.

3. Intelligence testing can be eliminated since Army General Classification Test (AGCT) scores are available for military test participants.

DI-H-1334A includes several requirements to assure that the selected test participants are representative of the user population. These requirements include the minimum numbers of participants used in the HFE test, the descriptions of the participants (12), and the training of participants.

Both the number and skill levels of the test personnel must be determined prior to testing. In general, the more participants tested, the more reliable the test results. However, the cost of conducting the test increases monotonically as the number of test participants increases. Tradeoffs must be made between data reliability and test costs. DI-H-1334A requires at least three participants per task group. The effect of test participant performance variability is an important factor in determining the number of test participants. In experimental prototype tests, participant variability, in terms of time requirements for monitoring static displays and adjusting static controls, may reflect test participant differences more than it does actual task response times. Thus, the minimum number of personnel required by DI-H-1334A (three participants) is generally sufficient to obtain the required frequency and sequence-of-use data derived from a static mock-up. Performance times and error rates obtained in tests of systems in advanced and engineering development are more representative of operational performance

than earlier test results. Therefore, a more precise estimate of performance may justify a larger sample size to reduce the measurement confidence limits. In general, four to six test participants should be sufficient to obtain reliable results at a reasonable cost. In the sample HFE tests, three participants were used in the experimental prototype (RPV) test, whereas five participants were used in the engineering development prototype (CCU) test.

To provide indices of the representativeness of the test participants as compared with the eventual user population, DI-H-1334A requires that measures of intelligence and other personnel characteristics be obtained and reported. If the test participants are civilian operators, professionally accepted, general intelligence tests are required (4, 7). The objective of such intelligence testing is to determine the representativeness of the sampled participants, rather than to measure exhaustively the participants' range of intelligence. Therefore, one or more short, paper-and-pencil tests of general intelligence should be quite sufficient. In the sample experimental prototype test where civilian operators were used, two well-established psychological tests (Otis-Lenon and Bennett Mechanical Comprehension) were used to test general intelligence. If military personnel are used as test participants, the Verbal Reasoning and Mathematical Aptitude scores of the Army General Classification Test (AGCT) may be used.

Additional measures required by DI-H-1334A include age, weight, body dimensions, visual acuity, and physical disabilities. The degree of precision required in these measurements is dictated by operator tasks identified in the task analysis. If the operator's tasks require extensive visual skills, additional tests of visual capabilities (e.g., depth perception, color perception, etc.) may be required. However, for the majority of tasks, a simple measure of acuity (e.g., Snellen eye chart or Armed Forces Clinical Visual Acuity Test) should be sufficient. Procedures for measuring visual capabilities have been documented (14, 23, 51). Similarly, only the body dimensions relevant to the successful and comfortable execution of the identified tasks should be recorded. Techniques for anthropometric measurement are given by Roebuck (45) and VanCott and Kinkade (78).

Test Participant Training. Equipment, no matter how appropriate for the given task, cannot be adequately evaluated unless test participants are suitably trained. Because untrained test participants can make a system look worse than it is, DI-H-1334A includes requirements to assure that the test participants are trained. The participants must be informed of their test duties, and their knowledge of the equipment and their tasks must be assessed prior to testing. Pre-test assessment of training assures that the test participants are, indeed, sufficiently prepared and trained for the test. Additionally, the pre-test training assessment data, in conjunction with the test data, can be valuable in estimating training requirements for the expected user personnel.

Assessment of test participants' abilities and knowledge is a critical concern of the developmental and operational testers, and is one of the major control features built into DI-H-1334A. Preassessing test participant abilities and knowledge provides information on whether the participants can

perform the required tasks adequately with the training provided along with providing baseline data for later testing. Pre-test knowledge is assessed by administrating paper-and-pencil achievement tests and/or by having operators perform required tasks on the test equipment. Items for the tests can be obtained from previous training tests, if any exist, or new questions can be derived from the task analysis. As an example, Appendix 1 contains the achievement test developed for the CCU training test. Procedures for developing training test questions, job sample tests, and for evaluating training programs are given in various texts (3, 14, 51) and selected MTP's (64, 69, 71).

The type and amount of pre-test training depend on the stage of system development and the uniqueness of the system. For a system in early development, or for a system that is a radical departure from earlier systems, trained operators will not be available. In these instances, thorough pre-test indoctrination will be required to introduce the participants to the equipment, operational procedures, and task requirements. For tests of systems in advanced stages of development, trained operators should be more readily available. In this latter case, pre-test training will consist of briefings on test procedures and performance requirements, and then a period of controlled practice.

Data Acquisition and Analysis Planning. Both objective and subjective data collection techniques are required to obtain the information required by DI-H-1334A. The distinguishing feature between the two is the source of information obtained. Information which depends on judgement or opinions of test engineers and/or test participants is classified as subjective. If the source of information entails measurement of man-machine system characteristics or performance, then the method is considered objective. Examples of subjective methods include ratings, rankings, questionnaires, and interviews. Objective methods include measurement of performance time, error rates, event frequencies, as well as the determination of dimensions, illumination levels, forces, noxious gases, etc.

In general, objective measures should be employed as much as possible, due to the following advantages:

1. The degree to which performance standards are met may be determined

2. Comparison of the obtained measurements with the criteria does not require subjective inference

3. The results are repeatable since error arising from human judgment is minimized.

Objective methods are most appropriate for answering two of the main questions posed by DI-H-1334A: the feasibility of task group performance and the adequacy of the man-machine interface. Objective performance assessment procedures are described by several authors (5, 8, 24, 40, 78) and in MIL-HDBK-759 (35).

A good technique of objective performance assessment is direct observation by a trained HFE test observer who uses a behavioral checklist (27) to assure that all of the required tasks are performed and to provide an orderly way of recording data. With this technique, an observer is required for each tested personnel position; and a different checklist will be used for each personnel position. The checklist is also used to record on-site comments and error descriptions. Appendix 2 contains a checklist used in one of the test segments of the CCU sample HFE test.

Greater reliability can be obtained by using objective observation techniques, supplemented by audio, video, and film monitoring. Audio recordings can be used to document sequence errors and task group communications. Video recordings are particularly useful in studying human performance to determine causes of errors, equipment incompatibilities and task group interference problems. Video recordings can also be edited (significant events can be highlighted) and used for presentations at design review meetings, etc.

Automated data collection and analysis techniques can also be used, particularly with a dynamic mock-up that is controlled by a computer. Automated techniques are often capable of providing considerably more accurate information than can be collected or analyzed within the test constraints. Automated data collection may be particularly useful in analyzing time and sequence-of-use events. However, the time required to develop the necessary data reduction and analysis software must be considered. If repetitive testing is envisioned, such software developments can be particularly cost-effective.

While objective measurements may indicate whether criteria are met, they may not provide an adequate explanation for substandard performance. It is here that subjective methods may be a valuable supplement for determining the causes of such problems. The person who operates or uses an item has firsthand knowledge of its operating characteristics. Consequently, evaluations should take advantage of the subjective opinions and observations of those who use, operate, and maintain equipment. To collect these observations, carefully planned, structured, face-to-face interviews are preferred. Questionnaires can also be used, or the two techniques may be used together.

Again, objective methods alone are insufficient for gathering data on the adequacy of personnel training and selection criteria. Subjective methods also are needed whenever it is necessary to obtain such information as the degree of user acceptability, motivation, comfort, or convenience.

Questionnaires and interviews help determine the causal factors to which system inefficiency can be related. Since the determination of causal factors is the only basis upon which corrective action can be taken, the data gained from the questionnaires and interviews are an extremely important part of the total data pool. However, since corrective action will, in many cases, have a high cost asssociated with it, care must be taken in the administration and subsequent interpretation of the data. While the data from the questionnaires and interviews will be supplemented by objective performance data, these data must also be able to stand alone as a useful data source. Appendix 3 contains an example questionnaire that was used in the sample tests.

Data obtained from interviews, checklists, and questionnaires are also useful in determining and analyzing test problems and errors. A sample HFE checklist is contained in Appendix 4. Interviewers and questionnaires should ask the test participants to describe and/or list the problems they experienced during testing and how they think their working environment, tasks, etc. could be changed to improve their performance. Information on potential safety hazards should also be solicited. All of these techniques for recording data complement one another in compiling the data needed for developing complete narrative descriptions of test problems and errors. In addition to the previous references given for objective assessment techniques, a further disucssion of subjective techniques has been recently published (62).

As stated in DI-H-1334A, the HFE test serves as the principal means of substantiating the feasibility of required human performance, the accuracy of the personnel selection criteria, the adequacy of the training program, and the acceptability of the man-machine interface. Therefore, the data to be collected must be useful in responding to these requirements. The task analysis identifies all of the tasks that the operator must perform. The data which are collected must indicate the time required to complete each task and must indicate the type and amount of errors in performing these tasks.

Data must also be gathered about human performance that is critical to mission success. Critical human performance is that which, if not accomplished in accordance with system requirements, will have adverse effects on cost, system reliability, efficiency, effectiveness, or safety. Human performance is considered critical whenever the test item's characteristics demand performance which challenges human capabilities--and which may therefore contribute significantly to conditions such as:

1. Jeopardizing performance of a mission

2. Delaying a mission beyond acceptable time limits

3. Causing improper operation that produces a system "no-go," inadvertent weapons firing, or failure to achieve operational readiness

4. Exceeding predicted times for maintenance tasks

5. Degrading system equipment below reliability requirements (mean time between failure (MTBF) is reduced)

6. Damaging system equipment so it must be returned to a maintenance facility for major repair, or causing unacceptable costs, spare requirements, or system downtime

7. Seriously compromising weapon system security

8. Injuring personnel.

Any evaluation, even one consisting only of questionnaire or interview data, will involve some sort of statistical summary and analysis. The statistical treatment may be relatively simple, involving no more than some

summary tables with averages or some other descriptive statistics, or it may be quite complex, encompassing curve fitting or analysis of variance. Whatever its nature or form, a statistical analysis can be no better than the data that enter into it. For this reason, the choice of data reduction procedures must be developed prior to testing and must be compatible with the data to be collected. When analysis procedures are established prior to testing, the test personnel can insure that all of the data required for the selected analysis are obtained during the testing. Several authors (5, 28, 30, 47, 79) describe data analysis techniques for the various types of data obtained from a DI-H-1334A application. Analysis techniques are also described in the Data Analysis section of this report.

Test Segment Development. The operator tasks that were identified in the task analysis must be scheduled so they occur in proper sequence during the test period. For some systems, the machines' operational sequence dictates the sequence of tasks. For example, in the sample test of the RPV control station, the vehicle's flight stage determines the order of control operations. Thus the task scenario was developed so it followed this natural sequence of operations. For other systems, tasks may be performed in irregular sequences, as with the CCU in the TACFIRE system. Here, the operator's task scenario was designed so it included all identified tasks. In both cases, the scenario included all tasks that had been identified in the task analysis. Appendix 5 presents a sample test scenario.

Where the preliminary hazard analysis of the system has identified potential safety problems, the test manager should insure that the test segments planned include performance of all tasks related to the hazards identified and that appropriate data (at minimum, the time and error dimensions of human performance; frequently, measures of equipment performance or environmental characteristics) will be obtained from which to determine whether each hazard predicted actually occurs and, if so, whether adequate safety measures exist to minimize its effect(s).

The test scenario can be written in a manner similar to a play script. To minimize paper shuffling during test execution, these scenarios should be combined with the behavioral checklists. The behavioral checklist includes the description of the task to be performed (scenario), the indication of correct performance, and columns for recording performance times and errors. Use of these checklists substantially reduced the effort required to collect human performance data in the sample tests.

Test Schedule Preparation. A schedule that specifies the segments and the operators to be evaluated at each test session should be developed prior to testing. If the schedule is followed, problems associated with what participants and segments are to be evaluated during any particular session should be minimized. Time estimates for completing all of the tasks required for each of the major segments of a task group are derived from the task analysis, from system designers, experienced personnel, or from performance standards, if they exist.

Test Dry Run Execution. After the test has been designed and all sessions have been scheduled, a preliminary run-through should be performed.

The purpose of this dry run is to evaluate the test to assure that all data can be recorded and that the test moves smoothly. For this preliminary test evaluation, substitute experienced operators or HFE test personnel for the test participants. This evaluation is used to assure that all tasks have been included and properly sequenced. This preliminary evaluation will identify potential test deficiencies and minimize false starts. However, this preliminary evaluation is not used to collect test data.

HFE Test Exeuction

Pretest Procedures. Before the test is conducted, several activities must occur with the test participants. A pretest session provides an opportunity to obtain biographical, anthropometric, and descriptive data from the participants (12). Pretest training and practice can also be given during this same period. Training evaluation testing should be completed before the HFE test is started to assure that all participants have been sufficiently trained to perform all required tasks. This training evaluation test may include a sample of the participants' performance on selected portions of the HFE test scenario. A performance sample supplements the job knowledge test in assessing a participant's readiness for testing. Criteria for accepting a participant for the HFE test include on-the-job knowledge and performance sample test scores, as well as the opinion of expert operators or instructors that the participant is ready for testing and motivated to participate in it.

Test Execution. The test is conducted according to the plan and sequences developed earlier. The test will usually require a minimum of two test personnel to direct the test activities, to observe test participant performance, including performance times, errors, and task group interference, and to record performance data.

The environmental measures should be recorded as often as scheduled in the test plan. Periods between successive participants provide convenient opportunities to record these measures. The final test session will include any questionnaires and interviews designed to obtain subjective measures of task group performance, and acceptability of the environment, adequacy of training, etc. To preclude test biases, previously tested participants should not be allowed to discuss the test with untested personnel.

Data Analysis

Objective and Subjective Data Summarization. In the experimental prototype phases of system testing, the HFE tests focus on determining the adequacy of the man-machine interface, the appropriateness of task allocations to man and machine, and the feasibility of task group performance. In that stage of development, the HFE data analysis focuses on sequence, frequency of use, and criticality of equipment components. Reliance on time and error rate data depends on the degree of realism in the simulation of control movements and display indications. For example, in a test of a static mock-up, the times required and the errors observed in actuating and adjusting controls and monitoring static displays may bear little resemblance to ultimate operational

times and errors. However, time and error data should be obtained to provide baseline rates for later test evaluations. To enhance the usefulness of these data for comparisons with subsequent data, measured performance times should be stated such that statistical treatments may be applied. Where the number of test participants is small, the raw data may be stated (as in Table 26). Otherwise, mean, standard deviation, and sample size should be reported. For error data, both the number of observed errors and the total number of opportunities for error should be stated for each task. In static mock-up tests, it is more appropriate to assess the interface, task allocation, and task feasibility indirectly by analyzing the design of the work space. Link analysis/work process charts may be used to derive frequency and sequence of use of all controls and displays used by the task group (see Table 14 for a sample of a work process chart). Psychological scaling techniques (rating, rank order, pair-comparison, etc.) are useful in determining the importance/criticality of all required equipment. Scaling data can be combined with frequency and sequence-of-use data to determine whether controls and display arrangement criteria (sequence and frequency of use, criticality, common functions, etc.) have been satisfied (36). Procedures for performing link/work process analyses have been described (5, 8), as have psychological scaling techniques (13, 18, 22).

Anthropometric suitability of the man-machine interface is assessed by comparing the layout of the work space to the standards contained in MIL-STD-1472B (36). The literature also contains procedures for evaluating anthropometric suitability (35, 45, 78).

For HFE tests in advanced and engineering development, the adequacy of the man-machine interface and human performance reliability and efficiency can be assessed directly by analyzing the obtained performance time and error data. Direct time and error rate assessment also apply to experimental prototype tests conducted on equipment or mock-ups that closely simulate operational equipment.

Data analysis techniques for determining the adequacy of the personnel selection criteria and the training program range from performing content analysis of interviews and questionnaires to summarizing personnel task times and error rates. Content analysis techniques are appropriate for both experimental prototype and advanced development tests. Dunnette (9), Guilford (13), and Guion (14) describe interview and questionnaire summary techniques. The observation of personnel response times and error rates is most appropriate during advanced and engineering development. Inadequacies in training and selection criteria are demonstrated by inappropriately long response times and a more or less even distribution of errors across all tasks (assuming the equipment interface is adequate and the task is feasible with the equipment provided). By comparing measured performance with performance standards (if they exist) and with the material covered in the participants' training course, training deficiencies can be determined. This information, along with the test participants' evaluation of their own training, provides inputs to determine training and personnel selection adequacy. Procedures for evaluating the adequacy of the training and selection are well documented (29, 51, 64, 69, 71).

Problem and Error Description. Within the military R&D community, there is a growing awareness of the relationship between the efficiency with which soldiers are able to operate and maintain equipment and the ultimate effectiveness of the man-materiel system (77).

> "People are the only responsible agents in the system. No matter how small the roles assigned to people, they are responsible roles. People determine whether the system is ready to operate, what it is to do, how and when it is to do it, when and what variations in performance are to occur, and what constitutes adequate or complete performance. People decide, control, guide, change, and evaluate. They are expected to anticipate, detect, compensate for, and explain any undesirable variations in performance. And their errors assume a significance commensurate with their responsibilities" (49).

Consequently, to evaluate system performance, one must have a fundamental understanding of the reliability of the human component. The beginning of that understanding is with the measurement of human performance errors. Errors can be defined as:

1. Performance of a required action incorrectly
2. Performance of a required action out of sequence
3. Failure to perform a required action
4. Failure to perform a required action within an allotted time period
5. Performance of a non-required action.

DI-H-1334A requires that frequencies, consequences, and causes of each error identified in the HFE test be completely specified. To assess the impact of the effects of human performance error on system performance, the frequency and consequences of the error must be determined. Error rates are obtained by deriving the following ratio for each error identified:

$$\text{Error rate} = \frac{\text{\# of times error committed}}{\text{total \# of times task performed}}$$

Error consequences can be obtained by performing a Failure Mode and Effects Analysis (FMEA), as described by several writers (8, 27, 33, 60). Procedures for identifying error causes include:

1. Direct observation of operator performance
2. Analyses of films or video recording of task group performance

Procedures for identifying the causes of human error are also described elsewhere (8, 11, 28). Error causes and alternative solutions and actions to eliminate or reduce errors should be fully described.

Man-Machine Incompatibilities. There are three general types of incompatibilities which the test manager should be alert to detect. Although all may spring from system design, each is manifested in a somewhat different way.

Task group interference occurs when an individual, performing his assigned tasks correctly and in their proper order, interferes with one or more other individuals who are attempting to perform their own tasks in the system. Examples include:

1. The requirement for two different people to use the same control at the same time but for different purposes

2. The requirement for one person to have performed Task A before another person can perform Task B; where Task B is now ready to be performed, but Task A has not yet been completed.

Equipment incompatibilities arise when two (or more) equipment subsystems (each of which may meet relevant human engineering design criteria) cannot be used together. Common examples of this are sound-attenuating ear muffs and helmets (which cannot be worn at the same time) and vehicle crewmen helmets and optical sights (where the thickness of the helmet prevents the gunner from attaining the proper eye relief on the browpad of the sight). A more sophisticated example was detected during the test of the RPV control station. The control-display relationships on the runway and glidescope monitor were found to be the reverse of those same relationships on the onboard video of the RPV; therefore, performance of a control input while observing one display would be likely to induce errors in control inputs made from observations of the other display.

The third general type of man-machine incompatibility is the classic human engineering problem of improper hardware design and its effect on the human operator. The scope of this category is broad and includes not only simple problems (such as equipment which is too heavy or controls which cannot be reached by the operator), but also equipment characteristics (e.g., vibration) which affect human performance and allocation of functions to human performance (such as software design which requires the operator to retain and recall more information than can be dealt with effectively).

Because the conduct of an HFE test in accordance with DI-H-1334A requires actual human performance of tasks on prototype hardware (or mock-up), an excellent opportunity is afforded for identifying safety hazards in operations and maintenance. Although a preliminary hazard analysis of the system will normally have been performed prior to the conduct of an HFE test (60), it is difficult in a paper study to anticipate all of the crew and operator equipment interactions which can create hazards. The HF test manager should review the preliminary hazard analysis prior to developing the test segments to insure those hazards are addressed (see Test Segment Development above). However, during the actual conduct of the test, the test manager should be alert to identify any other safety problems which may appear. Each hazard identified during testing should be described in paragraph 7 of the DI-H-1334A report. The frequency with which each hazard was encountered by the test participants should be stated and, if this frequency is not reflected in the data, the discrepancy should be explained. The possible consequences of each

hazard should be estimated whenever possible, with respect not only to personnel who may be affected but also with respect to system effectiveness and reliability. Where a hazard is identified prior to the HFE test, the DI-H-1334A report should state whether the procedures proposed to eliminate or minimize it were adequate. Where a hazard is identified as the result of the HFE test, the DI-H-1334A report should recommend alternatives for avoiding it. Several authors have described procedures for identifying and eliminating safety hazards (3, 51, 60).

DI-H-1334A requires that alternative solutions be proposed for all observed problems, errors, incompatibilities and hazards. Each proposed solution should be stated in terms of one or more of four possibilities:

1. Equipment redesign
2. Alteration of human performance tasks
3. Personnel selection criteria
4. Training

The alternative solutions proposed should reflect both the stage of system development and the HF engineer's appreciation of system life cycle cost. For example, if a problem amenable to a hardware fix was noted during the testing of an advanced development prototype, it would almost certainly be more cost-effective to make design changes during engineering development than to upgrade the eventual operator's selection criteria or extend his training. Hardware fixes involve non-recurring costs. Upgrading the QQPRI incurs costs which must be lived with for the life of the system.

Since the final choice of problem solution will be made by someone else, the HF engineer should provide enough detail in each of his alternative solutions (e.g., does a design solution refer only to one manufactured part or to an entire component) and the HF engineer's subsequent prediction of the changes in system performance which would accrue from adoption of each alternative proposed. The HF engineer is not expected to perform a Cost and Operational Effectiveness Analysis (COEA). The engineer should realize, however, that this section of the DI-H-1334A report may subsequently be used in such an analysis.

Human Performance Impact Assessment. As Howard and Lipsett have reported,

> Human-initiated malfunctions...account for 50 to 70 percent of all failures of major weapons and space systems... This places human error ahead of design error, component unreliability, and lapses of quality control in manufacturing--that is, ahead of electrical, mechanical, and structural failures as a source of system troubles. As a result, a reliability program which only addresses hardware spends 80 to 90 percent of its budgeted engineering cost and manpower to solve less than 50 percent of the total reliability problem (15).

One of the major reasons for conducting a DI-H-1334A evaluation is to determine the adequacy with which system personnel can perform assigned duties. The determination of the time required and the errors committed in performing assigned tasks is used to determine the impact of human performance on system effectiveness and reliability. Ideally, the impact of human performance is assessed by comparing measured task performance with required task performance standards. Various quantitative techniques have been developed to assess the impact of human performance in system reliability and effectiveness (8, 10, 25, 26, 27, 30, 32, 38, 43, 44, 48, 50). Basically, most of these techniques consist of conducting the following steps (30):

1. Perform a task analysis to determine the behavioral units (e.g., steps, subtasks, tasks) to which the prediction will be applied.

2. Analyze the behavioral units to determine which parameters must be considered in making the prediction. Typical parameters known to affect performance that might be considered are: organization of controls/displays, presence or absence of feedback information, accuracy required, environmental factors, etc. This step is often performed implicitly and only the most obvious parameters might be considered.

3. Assign the input data to the behavioral units whose performance is to be predicted. This involves the following steps:

   a. Determine the sources available for supplying the input data

   b. Match data parameters with those describing the units to be predicted (e.g., if the data have been collected under different conditions than those in the task being assessed, appropriate adjustments have to be made)

   c. Assign selected data to predictive units

4. Use a selected predictive method to obtain the desired output measures. This is achieved either by using probability statistics to combine behavioral units to take into account their interdependencies, or by employing simulation techniques to achieve the same end.

5. Finally, combine the predicted human reliability estimate with the corresponding hardware estimate to give an overall system reliability figure.

One of the measures from which an emerging system's ultimate effectiveness is normally predicted is its operational availability (A_O). Although there are a number of formulas for deriving A_O, most employ a term identified as Mean Time To Repair (MTTR) (15). This value may be calculated for the purpose of developmental testing from the DI-H-1334A data concerning performance times of maintenance tasks. However, the full contribution of human performance to A_O will not have been assessed unless the actual number of human errors (by category) measured during the DI-H-1334A test is compared with the

opportunities for error (27), and that ratio used either in the calculation of MTBF (Mean Time Between Failures) or whatever other term is used to determine the measured system performance reliability component of the A_o equation.

For many tested systems, human performance standards will not be available. In these cases, the impact of the operator's tested performance can be assessed by using assumed performance standards or by identifying a baseline task within the set of tested tasks which can provide a basis of comparison. Assumed performance standards can be generated on the basis of performance standards from similar systems or on the basis of tested performance of other task groups in the same system. When neither system performance specifications nor human performance specifications can be identified, then a baseline task technique can be used to provide a form of internal validity. In this technique, all obtained performance times and error rates are compared with performance on the task selected as a baseline. A task is selected as a baseline if it is (1) pervasive or representative of a wide range of operator duties, (2) performed with relatively few errors, and (3) performed with relatively small variations in performance times among test participants. This procedure is illustrated in the CCU sample test.

Differences between obtained task performance and either assumed standards or a baseline task should be described as in the case with stated performance standards. However, the same statistical tests may not be appropriate for discussing the reliability of the observed differences. In this case, the description may be given in terms of the qualitative impact of the tested operator performance on projected system performance (10, 30).

After the differences between obtained and required performances have been summarized, those obtained performances which are widely divergent from the standards should be analyzed to determine the reasons for the differences. This analysis will often be qualitative rather than quantitative, since the source of the differences may be obscure. In those instances where the performance is significantly poorer than the standard, the previous discussions of problems and errors may already have provided suggested causes and remedies for the poor performance. In the case of tested performance which is significantly better than the standard, the analysis should identify the sources of the superior performance and suggest whether the standard should be revised to account for these identified sources.

Report Preparation

The outline contained in Block 10 of DI-H-1334A provides a logical organization of all the required test items; therefore, this outline should be used to draft the test report. The two sample HFE tests are organized according to this outline and illustrate the format and amount of detail required. These sample reports can be used to resolve ambiguities which may arise while drafting a test report.

The first section of the test report is intended as an administrative introduction. This section includes a description of the personnel positions that were tested and a brief summary description of their work space, equipment, and major performance requirements. This section also includes the details of test administration, including test location and the personnel involved in conducting and supervising the test.

Section 2 deals with planning and conducting the HFE test. The first two paragraphs of this section include a detailed taxonomy of all tasks performed by each personnel position and the standards to which the tasks should be performed. The remaining paragraphs of Section 2 are devoted to descriptions of the test environment, participants, and procedures. Sufficient detail should be included to permit the reader to determine the degree to which the test conditions match the expected use conditions of the tested system. Those test conditions which differ from the expected use conditions are described in the final paragraph of the section.

Section 3 of the report describes the test design, methods, procedures and equipment used to collect the data. Where tradeoffs have been made in selecting among alternative designs and methods, the rationale for those selected should be stated.

Sections 4, 5, 6 and 7 give the results and describe the human performance errors and safety hazards observed during testing. Sufficient detail should be included in these sections so that test participants' performance times and errors--as well as their subjective responses--can be independently analyzed. However, extensive tables of raw data should be avoided except where essential to illustrate a problem or error.

Section 5 also describes the problems observed. In this context, a problem may be defined as the cause of an error. Even though an error may not have been observed during an HFE test, analysis may show that it will probably occur later. For example, during the CCU test, observers noted that the labels were wearing off the rubberized keys. It can reasonably be assumed that, when the labels become obscured, errors will occur. Such problems, together with their anticipated consequences and recommended solutions or corrections, should be described in the test report.

Section 8 of the report discusses the impact of the observed human performance on the reliability, availability and effectiveness of the tested system. The first subparagraph of this section calls for a statement of system performance goals to provide the standards by which the impact of observed performance can be assessed. Notice that these are overall <u>system</u> goals rather than the human performance goals that were identified previously in Section 2. Quantitative analyses and calculations should be included as much as possible to aid systems analysis personnel in combining the HFE test results in their calculations of overall system effectiveness.

Section 9 summarizes the HFE test's conclusions and recommendations. This summary highlights the test's primary findings, their estimated impacts on system performance, and recommended changes. It is especially important that this summary provide a comprehensive, clear, and concise description

of the results and recommendations, because other reports may use it as a summary of the HFE test's results.

REPORT OF HUMAN FACTORS TEST OF A SYSTEM IN EARLY DEVELOPMENT (MISSION CONTROL STATION OF COMPASS COPE)

This is a sample of an HFE test. The purpose of this report is to provide guidelines to contractors on how to conduct, analyze, and report HFE tests for a system in the conceptual (Experimental Prototype) stage of system development. The Pilot and Copilot task groups are the subject of this report. The report contains an evaluation of their respective task requirements, selection criteria, training programs, and equipment interfaces.

This report illustrates the contents and format for a test document prepared according to the specifications of DI-H-1334A.

INTRODUCTION

Task Group Identification

This report describes the procedures and results of a Human Factors Engineering (HFE) test of the Pilot and Copilot task groups of the proposed Compass COPE Remotely Piloted Vehicle (RPV) system. The Pilot and Copilot are responsible for tracking, monitoring, and controlling single or multiple remote vehicles during takeoff, en route, on-station, and landing phases of flight missions.

Task Group Summary

The Pilot and Copilot operate the equipment of the Ground Control Station (GCS), which is housed in a standard equipment shelter measuring approximately 8 x 8 x 20 feet. The GCS van contains the necessary equipment for:

1. Tracking, monitoring, and controlling multiple RPV's
2. Up-link transmission and down-link reception
3. Computer and data processing
4. Voice communication
5. Air conditioning and lighting
6. GCS system testing.

Each operator has a control console. The Pilot's console contains the controls and displays required for active manual control of a single RPV. Additional RPV's can be manually controlled from this station by sequentially selecting each vehicle for control. In addition, the Pilot's console contains a computer-driven Multi-Function Display (MFD) which can display single or multiple vehicle parameters. The Copilot/Flight Engineer's console includes the controls and displays required for multiple vehicle status monitoring and for single vehicle subsystems monitoring. This console also includes controls for redundant subsystems selection, as well as an MFD for selectable data display.

Test Site

The HFE test was conducted at Teledyne Ryan Aeronautical, San Diego, California, between February 9 and February 13, 1976. Test sessions were conducted daily between 0830 and 1630. The tests were supervised by Mr. Barry L. Berson and Ms. Marlene Artof, of Perceptronics, Inc.

HFE TEST PREPARATIONS

Pilot and Copilot's Task Groups

Operational Performance Requirements. Tables 9 and 10 show sequential lists of Pilot and Copilot tasks and subtasks for all phases of a mission. The Pilot serves as the overall mission commander and performs the tasks required for manual control and automatic systems monitoring in single RPV operations. These single vehicle tasks are particularly prevalent during takeoff and landing operations and during emergency or non-normal en route operations.

The Copilot/Flight Engineer performs somewhat differently from a Copilot on board a manned aircraft. In the RPV system, the Copilot's tasks include monitoring and systems management for all vehicles under GCS control. This monitoring function applies particularly to the several RPV's that are flying under fully automatic control while the Pilot attends to a single vehicle under partial manual control. The Copilot/Flight Engineer's tasks also include calculating takeoff and landing parameters, attending to navigational problems, communicating with various radio-linked groups for flight clearances and advisories, and entering flight plan changes into the computer.

Maintenance Performance Requirements. The crew members (Pilot and Copilot) are not expected to perform any maintenance functions other than adjusting the front panel controls. The preliminary maintenance concept for the Compass COPE system is to have an on-line backup van ready to assume control of the RPV's in case major equipment components in the primary van malfunction. In the event of a catastrophic GCS equipment failure, the crew members would transfer to the backup control van while a general maintenance team repaired the primary van. For a non-catastrophic but annoying failure, a maintenance technician would repair the device during a lull in the mission period.

Human Performance Standards

The Compass COPE system requires simultaneous remote control of up to five flight vehicles. The design of the system requires the controllers to monitor the automatic operation of the vehicles and to control manually one of the vehicles during selected routine mission phases and during emergencies. Therefore, the operators must have sufficient information and control capability to decide when to assume manual control, to control a vehicle accurately, and to monitor other vehicles under automatic control. However, specific human performance standards for the task groups have not yet been developed.

TABLE 9

Pilot's Tasks and Subtasks

TASK 1: PERFORM PRE-TAXI OPERATIONS

Subtasks

1.1 Read (out loud) Subsystem Parameters to copilot
- a) Propulsion
- b) Electrical
- c) Flight Control System (FCS)
- d) Hydraulic
- e) Environment
- f) Prime Mission Equipment (PME)

1.2 Turn on Weather Radar (WR)
1.3 Verify the Weather Radar is operational
1.4 Command Crew Chief (CC) to start engine
1.5 Verify vehicle on internal power
1.6 Call out radar range to Radar Technician (RT)
1.7 Set Federal Aviation Administration (FAA) Transponder to correct frequency
1.8 Set FAA UHF relay link
1.9 Set brakes on
1.10 Command CC to install safety pins
1.11 Monitor Subsystems
1.12 Command CC to pull umbilical
1.13 Read (out loud) subsystem parameters to copilot
- a) Propulsion
- b) Electrical
- c) FCS
- d) Hydraulic
- e) Environment
- f) PME

1.14 Zero all command controls
1.15 Verify redundant systems are operational
1.16 Turn TV system on
1.17 Verify video on wideband data
1.18 Adjust zoom
1.19 Adjust CRT if required
1.20 Verify brakes and gear operational

TASK 2: TAXI RPV TO RUNWAY

Subtasks

2.1 Increase RPM
2.2 Release brakes
2.3 Monitor TV
2.4 Maneuver joystick for taxi on runway
2.5 Set brake
2.6 Continue to taxi, steering as required
2.7 Communicate with CC to check if wings are level
2.8 Proceed to runway
- a) Set brakes
- b) Increase RPM
- c) Steer as required

2.9 Verify RPV on track and steer to runway heading
2.10 Set RPM to idle
2.11 Set Automatic Flight Control System (AFCS) control to takeoff
2.12 Verify with RT that radar altimeter is on
2.13 Verify with CC that RPV is ready

TASK 3: PERFORM TAKEOFF PROCEDURES

Subtasks

3.1 Increase RPM
3.2 Read (out loud) subsystem parameters to copilot

TASK 3: PERFORM TAKEOFF PROCEDURES (continued)

3.6 Set Electronic Altitude and Direction Indicator (EADI) controls for TakeOff (TO)
3.7 Choose Air Traffic Control (ATC) countdown
3.8 Set clock
3.9 Set intermediate altitude
3.10 Switch brakes off
3.11 Set RPM for takeoff
3.12 Monitor video and steer as required
3.13 Verify airspeed and runway distance is exceeding abort criteria
3.14 Verify rotation and initial climbout on EADI
3.15 Monitor altitude
3.16 Turn to climbout heading
3.17 Reset airspeed trim to Ø
3.18 Adjust video as required
3.19 Hold altitude as required to clear aircraft (AC)
3.20 Test left and right turns
3.21 Check left and right slue capability
3.22 Check RPM
3.23 Command landing gear up
3.24 Monitor vertical and airspeed trim changes
3.25 Monitor FCS data
3.26 Check subsystem parameters for normalcy

TASK 4: ASSUME CONTROL OF RPV FROM THE RUNWAY CONTROL FACILITY

Subtasks

4.1 Verify subsystem status and significant events with RCF
4.2 Countdown for handoff
4.3 Assume control of the RPV
4.4 Verification of handoff
4.5 Verify control of each RPV

TASK 5: CONTROL AND MONITOR RPV'S DURING EN ROUTE PHASE OF THE MISSION

Subtasks

5.1 Turn TV system off
5.2 Turn on WR
5.3 Monitor WR display
5.4 Continually monitor subsystem parameters
5.5 Assume manual control of an RPV to alter headings or to remedy equipment malfunctions
5.6 Verify with RT that all RPV's are on appropriate track

TASK 6: CONTROL AND MONITOR RPV'S DURING THE MISSION PHASE

Subtasks

6.1 Turn on PME at the initiation point
6.2 Verify with Mission Control (MC) that PME is on and acquiring desired data
6.3 Adjust programmed flight plans of RPV if required
6.4 Continually monitor RPV subsystems during the mission
6.5 Turn PME off when mission is completed

(continued)

TASK 7: CONTROL AND MONITOR RPV'S DURING THE RETURN PHASE OF THE MISSION

Subtasks

7.1 Turn off mission program flight plan
7.2 Set RPV to cruise mode
7.3 Check control of each RPV
7.4 Continually monitor subsystem parameters
7.5 Assume manual control of an RPV if required
7.6 Verify all RPVs are on track

TASK 8: LAND RPVs

Subtasks

8.1 Lower landing gear
8.2 Verify landing gear is on and locked
8.3 Extend spoilers
8.4 Monitor environmental indicators
8.5 Monitor FCS display
8.6 Select glide slope
8.7 Get turnaround if required
8.8 Command landing mode
8.9 Turn on video
8.10 Adjust zoom
8.11 Adjust CRT
8.12 Lower flaps
8.13 Verify spoilers are active
8.14 Set and monitor flap
8.15 Monitor subsystem parameters
8.16 Check fuel remaining
8.17 Command landing mode on
8.18 Acquire RPV track
8.19 Command couple/glide slope
8.20 Set up EADI data presentation
8.21 Set automatic landing on
8.22 Communicate with CC about landing prediction
8.23 Switch landing lights on
8.24 Switch brake off
8.25 Align RPV with runway
8.26 Monitor
a) MLS
b) FCS
c) Altitude
d) Video

TASK 8: LAND RPVs (continued)

8.27 Adjust video zoom
8.28 Set airspeed trim
8.29 Adjust RPM
8.30 Set vertical trim
8.31 Adjust RPV attitude
8.32 Monitor crab angle and adjust as required
8.33 Enable nose steering
8.34 Monitor video
8.35 Monitor MLS
8.36 Steer as required
8.37 Monitor decrab
8.38 Monitor video
8.39 Monitor track on video display
8.40 Acquire data from squat switch
8.41 Land RPV
8.42 Monitor decrease in airspeed
8.43 Monitor braking
8.44 Adjust RPM for ground idle
8.45 Switch spoilers to full out

TASK 9: STEER RPVs OFF RUNWAY

Subtasks

9.1 Steer RPV manually down runway
9.2 Set brakes on at specified airspeed
9.3 Monitor airspeed
9.4 Monitor video
9.5 Monitor steering
9.6 Set brakes off
9.7 Adjust RPM as required
9.8 Steer as required
9.9 Set brakes on at parking spot
9.10 Command CC to install safety pin
9.11 Command CC to turn off fuel
9.12 Shutdown vehicle subsystems
a) Electrical
b) Engine
c) TV video
9.13 Switch flaps up
9.14 Switch downlink antenna off
9.15 Switch landing light off
9.16 Switch radar altimeter off
9.17 Turn off mission recorder
9.18 Fill out mission reports

(concluded)

TABLE 10

Copilot's Tasks and Subtasks

TASK 1: PRE-TAXI

Subtasks

1.1 Monitor the following subsystem parameters
- a) Propulsion
- b) Electrical
- c) FCS
- d) Hydraulic
- e) Environment
- f) PME

1.2 Call all other control facilities; verify on line and available

1.3 Verify beacons are operational

1.4 Set FAA relay link

1.5 Verify flight-plan clearance w/Air Traffic Control (ATC)

1.6 Obtain range clearance from ATC

1.7 Notify tower of status

1.8 Notify chase aircraft of status

1.9 Notify MC of status

1.10 Obtain weather clearance data

1.11 Perform Microwave Landing System (MLS) self-test

1.12 Monitor subsystem parameters

1.13 Command RT to adjust down-link antenna

1.14 Verify redundant systems are operational

1.15 Command RT to set antenna

TASK 2: MONITOR RPVs DURING TAXI PHASE

Subtasks

2.1 Receive clearance to taxi from tower

2.2 Verify MLS on and coupled

2.3 Command RT to verify antenna selected

TASK 3: MONITOR RPVs DURING TAKEOFF

Subtasks

3.1 Obtain ATC clearance

3.2 Monitor subsystem status

3.3 Monitor weather displays

3.4 Set Identify Friend/Foe (IFF) code

3.5 Determine abort criteria -time, airspeed, distance

3.6 Determine flap settings and call out to pilot

3.7 Determine EADI settings and call out to pilot

3.8 Command RT to set down-link antenna

3.9 Notify tower of takeoff

3.10 Notify all stations of takeoff

3.11 Monitor distance/turn up airspeed for aborted TO

3.12 Call out airspeed to pilot

3.13 Monitor all subsystems

3.14 Command RT to check antenna

3.15 Verify TO okay

3.16 Monitor video for weather conditions

3.17 Call out climb heading to pilot

3.18 Verify that range radar and beacon track are operational

3.19 Verify IFF track with ATC

3.20 Set Ident/Flash switch

3.21 Verify control of RPV by checking with chase AC

3.22 Monitor data for trim changes

3.23 Monitor subsystem parameters

TASK 4: ASSUME CONTROL OF RPV FROM THE RUNWAY CONTROL FACILITY

Subtasks

4.1 Establish communication with the Runway Control Facility (RCF)

4.2 Verify MCF #2 is on line and available

4.3 Command RT to verify down-link communication

4.4 Receive report of subsystem status and significant events from RCF

4.5 Verify plotting on CRT/plot board

4.6 Verify control of RPVs w/RCF, MCF, #2, ATC, Range

TASK 5: MONITOR RPVs DURING THE EN ROUTE PHASE OF THE MISSION

Subtasks

5.1 Turn WR on

5.2 Set WR track angle

5.3 Set WR gain

5.4 Set WR pulse

5.5 Set WR sector

5.6 Test WR-on "green"

5.7 Adjust the WR display

5.8 Monitor WR data

5.9 Set up for programmed pattern

5.10 Verify and calculate navigation settings for RPVs

5.11 Correlate RPV positions with MC

(continued)

TASK 6: MISSION

Subtasks

6.1 Verify that the PME is on

6.2 Communicate with MC

6.3 Command RT to adjust antenna

6.4 At initiation point, initiate program pattern

6.5 Communicate with MC

6.6 Adjust flight plan per prime MC command

6.7 Prepare new navigation parameters

6.8 Verify and input navigation pattern into airborne system

6.9 Coordinate with ATC for revised flight track pattern

6.10 Verify new pattern with prime MC

6.11 Correlate with MCF #2, RT, and pilot

6.12 Verify flight plan parameters

6.13 Check subsystems status

6.14 Obtain weather update in landing area from tower

6.15 Verify that the PME is off

6.16 Notify ATC RPVs returning to base

6.17 Monitor electrical system data

6.18 Turn on WR

6.19 Adjust WR as required

TASK 7: MONITOR RPVs DURING THE RETURN PHASE OF THE MISSION

Subtasks

7.1 Obtain en route weather data

7.2 Obtain predicted landing weather data

7.3 Notify RCF for recovery

7.4 Notify MCF #2 of return

7.5 Advise predicted landing time to ATC/tower

7.6 Turn program pattern off; turn cruise mode on

7.7 Monitor TV for traffic and weather changes

7.8 Report position and altitude to ATC/tower

7.9 Monitor engine and FCS subsystems

7.10 Monitor environment subsystems

7.11 Monitor environment displays

7.12 Report subsystem status and significant events to RCF

7.13 Verify plot/tracing position of MCF/RCF

TASK 8: MONITOR RPVs DURING LANDING

Subtasks

8.1 Obtain runway selection from ATC

8.2 Turn MLS on

8.3 Perform MLS test

8.4 Obtain runway clearance data

8.5 Monitor environmental data

8.6 Determine RPV weight

8.7 Command RT to select MLS antenna

8.8 Turn off WR

8.9 Check with ATC for radar vectors

8.10 Advise ATC of altitude during descent

8.11 Advise tower of the following

a) Request for approach

b) For downwind

c) On base

d) Turning to final

8.12 Verify MLS is operational

8.13 Report status to ATC/tower

8.14 Verify control is accepted by MLS

8.15 Establish go around criteria

8.16 Advise tower of final approach--distance and altitude

8.17 Monitor MLS, FCS, and altitude

8.18 Verify wind, RPV, weight, and temperature condition

8.19 Advise ATC of landing

TASK 9: PERFORM RPV POST-LANDING DUTIES

Subtasks

9.1 Verify MLS is decoupled

9.2 Monitor and call out airspeed

9.3 Turn off MLS

9.4 Request ground control clearance to taxi

9.5 Turn off WR

9.6 Record time of landing, power down

9.7 Prepare mission reports

9.8 Call out systems to be shut down: electrical, engine, TV video, etc.

9.9 Advise ATC, tower, and MC, "Mission complete"

9.10 Communicate to all facilities "Close of flight"

(concluded)

Test Environment

An air conditioned, carpeted, and draped conference room at Teledyne Ryan Aeronautical was used for testing. The room was located in a vacant section of one of their buildings. Components from the TECOM HFE instrument package were used to record the following environmental conditions:

Instrument	Measure
Spectra[R] Photometer	Illumination
Psychro-Dyne Psychrometer	Temperature and Relative Humidity
Precision Sound Level Meter and Analyzer	Steady State Noise

Each measure was recorded on the first and last test days. Environmental measures were not recorded more frequently because the test was conducted in an unchanging environment. The measures were replicated during the last day of testing to verify the environment's stability. Table 11 presents the mean, standard deviation and number of times each measure was recorded. The small standard deviations demonstrate the stability of the environment.

Test Participants

Three Teledyne Ryan personnel served as the participants for the HFE test. Participant characteristics are summarized in Table 12. A GPM anthropological instrument kit was used to record participant anthropometric data. Since operational personnel will be seated during mission performance, detailed measurements for seated operators were obtained. Two tests were administered to assess the participants' intellectual capabilities. The Otis-Lennon Mental Ability Test (Form J) was administered to obtain a measure of the participants' general verbal and mathematical skills. The Bennett Mechanical Comprehension Test (Form S) was administered to each participant to assess their mechanical and spatial aptitudes. Test results are contained in Table 12.

The participants' professional backgrounds and flight/RPV experience are listed below:

PARTICIPANT	PROFESSIONAL POSITION	FLIGHT/RPV EXPERIENCE
1	Human Factors Engineer	Instrument Instructor Pilot
2	Systems Engineer	Experienced RPV and Air Traffic Controller
3	Systems Engineer	Experienced RPV Controller

TABLE 11

GCS Environmental Recordings

	Average Reading	Standard Deviation	N
Illumination (Ft. candles)			
a. Console Desk Top	156	1.2	2
b. Console Front Panel	150	.4	2
Temperature	23°C	2.8	10
Relative Humidity	45%	2.4	10
Steady State Noise (db SPL) (Weighting)			
a. A	45	1.2	2
b. B	46	.58	2
c. C	50	1.3	2
d. Flat	54	.86	2

TABLE 12

Characteristics of Test Participants

VARIABLE	PARTICIPANT 1	2	3
AGE (years)	43	34	52
WEIGHT (pounds)	168	155	195
FLIGHT EXPERIENCE (years)	21	0	0
RPV EXPERIENCE (years)	9 (Engineering only; no flight experience)	5	10
ATC EXPERIENCE (years)	0	0	6
SCHOOL (last year completed)	M.S.	B.S.	3rd-year College
VISUAL ACUITY	20/20	20/25	20/20
PHYSICAL DISABILITIES	None	None	None
OTIS-LENNON PERCENTILE RANK*	97%	84%	76%
BENNETT PERCENTILE RANK*	97%	98%	99%

BODY DIMENSIONS (inches)	PARTICIPANT 1	2	3
STANDING HEIGHT	69	66	73
SITTING HEIGHT	49.6	49.6	50.8
SITTING EYE HEIGHT	45.4	45.3	47.5
ELBOW RESTING HEIGHT	26	26.1	25.9
HORIZONTAL ARM REACH	30.6	28.1	32.5
VERTICAL ARM REACH	51.5	48.4	52
ELBOW-FINGERTIP REACH	18.4	17.6	20.2
BUTTOCK-HEEL LENGTH	44.8	40.5	46.3

*Twelfth-Grade High School students used as the reference group (Otis Lennon, N=1500; Bennett, N=2350)

Test Participants' Clothing and Personal Equipment

Compass COPE missions will be directed from environmentally controlled vans. Operational personnel are expected to be dressed in working uniforms without protective masks. The test participants were dressed in their normal working attire (shirt, tie, and slacks), which is comparable to uniforms worn by military personnel performing desk-type duties.

Participant Training

The participants were selected on the basis of their previous experience. All were familiar with aircraft and RPV control. Each of the operators received two hours of training on the day prior to the first test day. During this two-hour period, the operators:

1. Became familiar with the configuration of the mock-up

2. Received instructions on how the test was to be conducted

3. Practiced the test segment tasks for 1-1/2 hours.

Before each test segment began, the operators were briefed. Each task listed in the scenario, and operator response requirements for those tasks, was discussed prior to testing.

Test Equipment

A full scale static mock-up of the GCS console (Figure 3) was used to conduct the HFE test. The mock-up was made of plywood and sheet metal. Strips of magnetic material held the simulated equipment components in place. The push buttons were color coded to indicate control conditions. Four sets of buttons were used to change control states. The following color coding scheme was used:

ON = blue	CAUTION = yellow
OFF = white	DANGER = red

The dimensions of the control console are given in Figure 4. Figure 5 shows the details of the mock-up's front panel.

Deviations of Test From Expected Use Conditions

1. Static controls and displays were used during testing

2. Highly experienced, single drone, RPV controllers were used as test participants

3. Test mission times were truncated (operational mission may last up to thirty hours; test missions required about three hours to complete).

Figure 3. Static mock-up of the Ground Control Station (GCS)

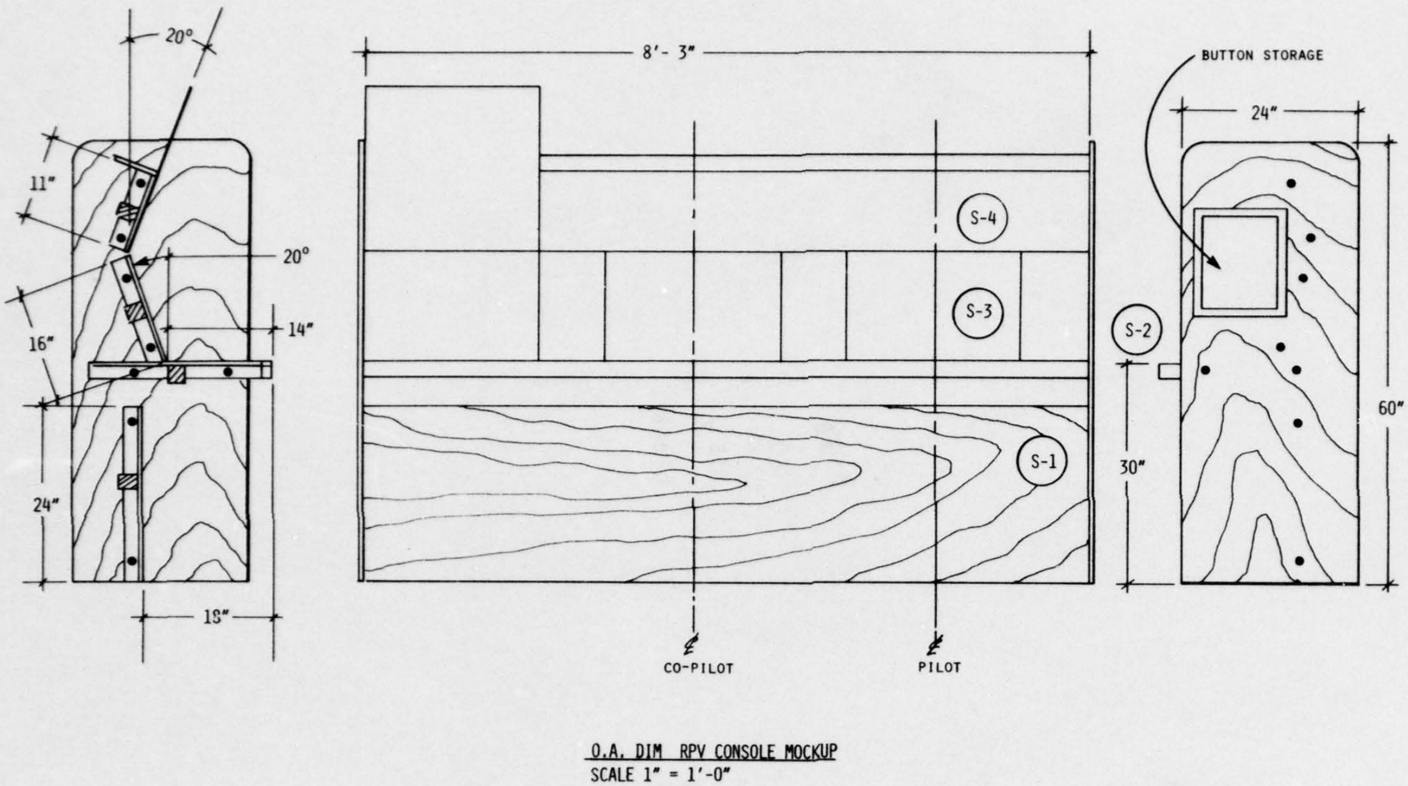
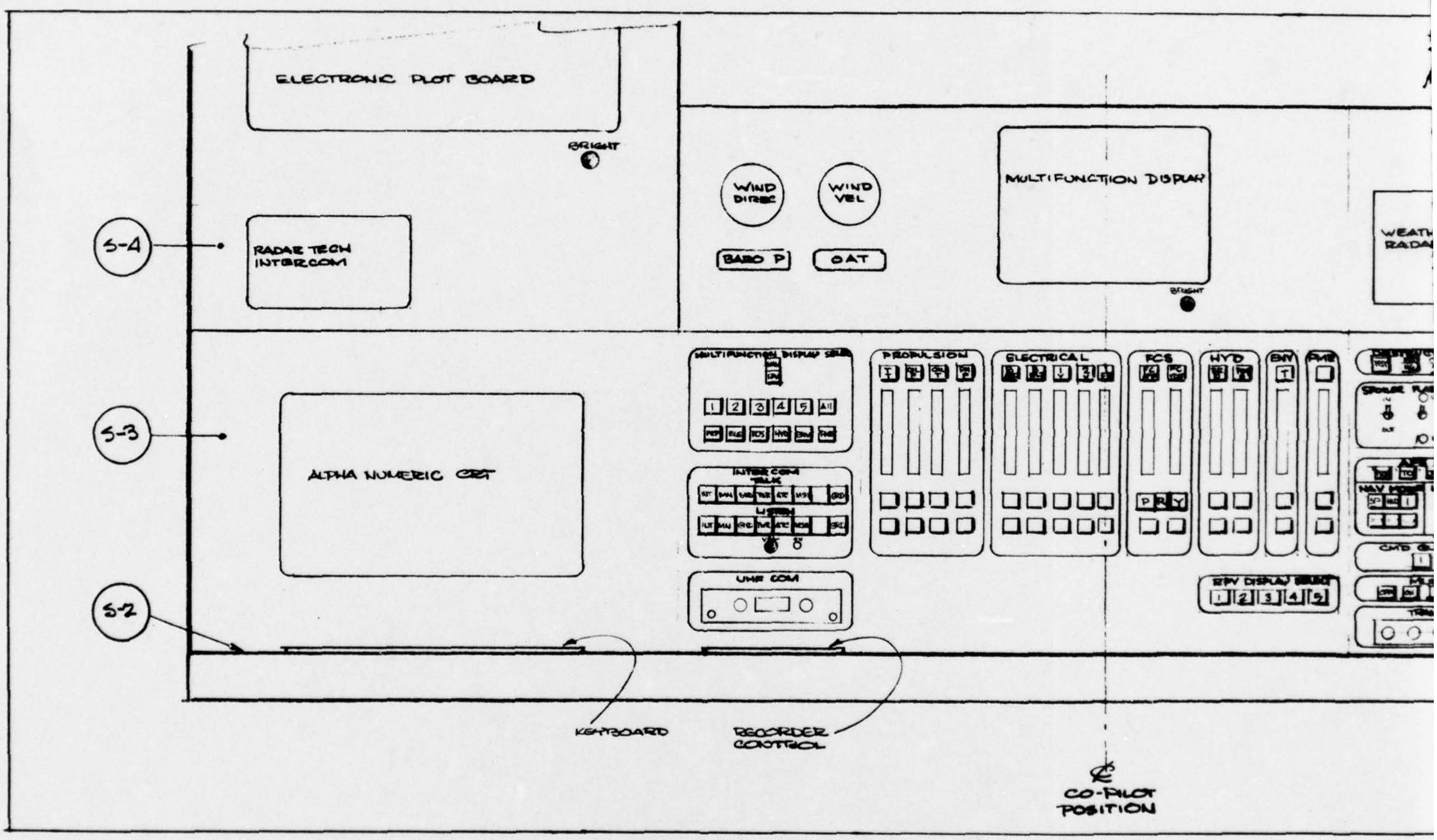
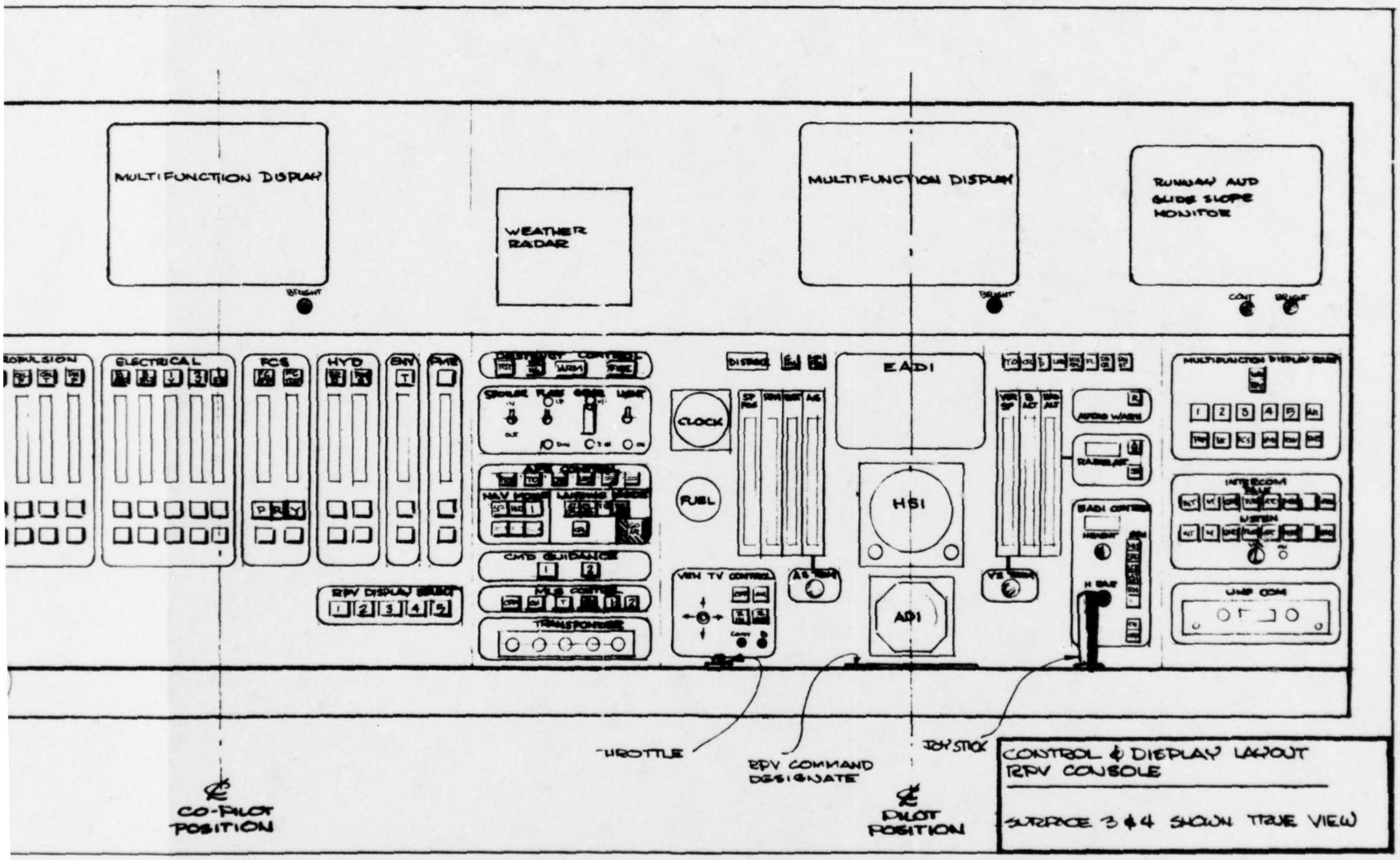


Figure 4. Dimensions of GCS Console Mock-up



1

Figure 5. Details of GCS mock-up front panel (Foldout)



2

. Details of GCS mock-up front panel
(Foldout)

These deviations reflect the early stage of design for the RPV control stations where dynamic simulations have yet to be developed and personnel have yet to be selected or trained. The focus of this HFE test includes determining (1) the feasibility of assigned operator tasks, (2) the adequacy of work space layout, and (3) whether all required displays and controls are included. The deviations did not affect the obtained data.

DATA COLLECTION TECHNIQUES

Test Plan

The test design consisted of testing each of the three operators in all six of the test segments. The segments included performing normal and contingency/emergency takeoffs, missions, and landings. In the normal segments, no equipment malfunctions were simulated. In the contingency/emergency segments, equipment malfunctions and flight plan changes were simulated to assess how the burden of these occurrences affects operator performance.

Each operator was tested at both of the personnel positions for each of the six segments. A total of six sessions was conducted. Two operators were evaluated during a session. Each session consisted of three segments. The plan for this study is shown below. The numbers listed under Pilot and Copilot indicate test operator number. Each session lasted about three hours.

	TEST PARTICIPANT		
TEST SESSION	PILOT POSITION	COPILOT POSITION	TEST SEGMENTS
1	1	2	1, 2, and 3
2	3	1	1, 2, and 3
3	2	3	1, 2, and 3
4	2	1	4, 5, and 6
5	1	3	4, 5, and 6
6	3	2	4, 5, and 6

Data Collection Methods and Equipment

Both objective performance and subjective questionnaire techniques were used to obtain the information necessary for evaluating the Pilot and Copilot task groups. The data collection methods used included:

1. Behavioral checklist
2. Operator questionnaire
3. Human factors operations checklist

4. End of test session interview

5. Control and display criticality card sort.

The primary method for collecting operator performance data was the behavioral checklist. Checklists were developed for each task group and test segment. Each checklist contained:

1. A sequential list of all operator tasks

2. Descriptions of the required operator responses for each required task

3. Columns for recording task response duration, response adequacy (correct/error) and error descriptions.

On the checklist, the tasks were arranged in the same order that the operators performed them. To evaluate operator responses, the test monitors would observe the respective operator's response and compare it to the response required, as shown on the checklist. When the operator performed the task, the test monitor would place a check (✓) in the appropriate column of the checklist. If the operator erred, the test monitor would record a brief description of the error in the appropriate column. The test participants' comments about task sequencing, adequacy of workspace configuration, etc., were also recorded on the checklist.

The procedures for collecting performance data were the same for each of the six test segments. Prior to testing, the test participants were given scripts. These scripts consisted of a detailed description of Pilot and Copilot task requirements. Since a high percentage of operator tasks involved interaction between the two operators, the scripts contained descriptions of both operators' tasks. These scripts allowed the operators to coordinate their activities by telling them what each operator was required to do and when he was to do it. To insure that testing would run smoothly, each task listed on the scripts was fully discussed prior to testing.

A test monitor observed and evaluated the performance of each participant. Each test monitor used a stopwatch to determine the task response times. Task response times were measured from the time the test director said, "Start task" until the participant said, "Task completed." A black and white video tape recorder was used to record problems and errors, and to obtain documentary footage. A cassette tape recorder was used to obtain audio recordings of the operators' communications.

Data Reduction Methods

The data from this test of a system in the experimental prototype stage of development are primarily frequency data, thus the most appropriate method of summarizing such data was to calculate the means and standard deviations. In summarizing the questionnaires, the test participants' suggestions and comments are arranged logically, but reported directly. For the criticality

and frequency of use ratings of controls and displays, rank order correlations and coefficients of concordance were calculated, with a 5% confidence level used in both cases.

HFE TEST RESULTS

This section presents results of the HFE test of the RPV Pilot and Copilot personnel positions. It summarizes the results of both objective performance and subjective questionnaire data.

Performance Data

Results for each of the six test segments are summarized below. Table 13 gives the mean times the Pilot and Copilot required to complete each task segment. The times indicated reflect the time required to perform the required tasks. On many tasks, the Copilot completed his requirements before the Pilot completed his. This is indicated by the longer segment times listed for the Pilot.

Normal Takeoff, Mission, and Landing Test Segments. No equipment malfunctions or requests for course changes were simulated in the first three test segments. The Pilot and Copilot were required to perform all of the tasks listed in Tables 9 and 10 for these three segments. In the normal takeoff and landing segments, the operators were required to track, monitor, and control a single RPV. In the normal mission segment, they were required to handle three RPV's.

Simulated Failures in Takeoff, Mission, and Landing Test Segments. In test segments four through six, the operators were required to perform all of the tasks required in the first three segments plus additional tasks imposed by simulated equipment malfunctions and requests to alter the course of several RPV's. The operators were required to perform takeoff, mission, and landing operations with one, three, and two RPV's respectively.

Questionnaire Data

Operator Questionnaire. Participants were asked to fill out a questionnaire which covered the following areas:

1. Biographic data (summarized previously in Table 12)
2. Training and experience
3. RPV operating procedures
4. Task interest
5. Man-machine interface.

TABLE 13

Task-Segment Times for Pilot and Copilot

	PILOT		COPILOT	
TASK SEGMENT	MEAN	SD	MEAN	SD
1	21.3	3.6	16.4	2.1
2	15.3	1.4	13.6	1.5
3	11.5	2.0	9.0	5.2
4	19.8	5.5	14.7	4.0
5	21.1	6.7	22.2	8.6
6	18.5	4.5	15.6	6.2
TOTAL =	107.5 Minutes		91.5 Minutes	

Times for each segment were recorded for all three subjects.

The participants filled out the biographical section of the questionnaire before testing and completed the questionnaire after they had finished testing. For the task interest and man-machine interface sections of the questionnaire, the test participants were told to imagine themselves in the expected operational environment and to answer the questions accordingly. The major findings are summarized in the following paragraphs.

Participant Training and Experience. The experience of the participants varied widely. Two of the participants were experienced RPV operators, one having six years experience in RPV range control. The third participant had an instrument pilot rating and twenty-one years of flying experience. Collectively, the participants felt that some previous experience in fields such as systems engineering, air traffic control, radio communication, and aviation was essential for RPV Pilots and Copilots. Table 14 shows the amount of time the participants felt trainees should spend on types of training, and training for areas of proficiency, respectively.

Task Interest. All participants found the task of operating RPV's interesting. The participants thought that the mean onset time for boredom would be about two hours, while the mean onset time for fatigue would be about four hours. One operator suggested that length-of-duty should be dependent on mission phase.

RPV Operating Procedures. Participants felt that duties in such areas as handoffs between control facilities and other tasks requiring coordination should be further defined because these operations are so complex. Coordination procedures will be studied, and recommendations will be made later in system development.

Man-Machine Interface. The participants made the following suggestions about the man-machine interface:

1. Relocate RPV select controls from desk top to upright panel

2. Relocate go-around switch to position on upright panel near throttle control

3. Place status indicators directly above EADI rather than to the side

4. Move video monitor controls to EADI panel

5. Slant Pilot and Copilot panels for better cross correlation of data and to reduce parallax when reading other position's data

6. Add oil quantity or low oil quantity indicator

7. Add MLS indicator for operation/failure

8. Add flap position indicator

9. Add fuel off arm/fuel off command controls.

TABLE 14

Estimated Training Time for Each Area of Proficiency

TRAINING AREA	RECOMMENDED TRAINING TIME (HOURS)	
	MEAN	SD
Operation of RPV System	67	18.4
Checkout of RPV System	42	10.2
Takeoff	10	3.4
Cruise climb	10	2.8
Descent	10	4.8
Approach and landing	78	20.3
Operation of GCS TV monitor	16	5.4
Takeoff-abort	8	6.6
Landing wave-off	16	3.8
Safety and emergency procedures	40	9.6
Flight restrictions	20	5.3
Radio-voice communication techniques, procedures, etc.	13	4.6
Backup system operation	19	6.3
Multiple RPV operation	100	24.8

N=3

10. Add takeoff-abort switch.

11. Add fuel pressure indicator.

12. Add arm rest for side controller.

13. Add glide-scope command.

14. Add glide-scope display video monitor.

15. AFS control panel should have an indicator for RPV under control.

16. Pattern plotter should show track and predicted plot.

17. Need destruct-armed indicator.

18. Need a "tie in" from joystick to flight program indicator and/or to audio alarm, in case joystick is inadvertently touched and RPV goes off programmed flight.

Criticisms made by participants included:

1. Main Plotboard: Distance of main plotboard from Pilot and Copilot positions makes it difficult to view the plotboard.

2. Command Designate Switch: If Pilot does not designate the appropriate RPV, Copilot's command goes to wrong RPV.

3. Video Monitor: Current display format leads to altitude and orientation errors.

4. Airspeed and Vertical Trim: No indicator showing that the RPV accepts the value set.

All participants felt that their operating positions were comfortable and that there was no difficulty in reaching controls.

Human Factors Operation Checklist

Each participant filled out a Human Factors Operation Checklist. The problems that were reported are listed below:

1. Not all operators requiring information from a common display have a clear line of sight from their operating positions.

2. Not all primary controls and displays are placed within the readily accessible visual and manual spaces on the console.

3. Emergency controls and displays are not placed in readily accessible positions.

4. In some cases, the operator's hand blocks the view of a display when operating the associated control.

5. Some displays cannot be read easily from the normal location of the operator requiring the information.

6. Controls associated with the right hand are not always located below or to the right of their displays and vice versa for controls operated by the left hand.

7. Shapes of controls cannot always be discerned by touch.

Criticality, Frequency, and Sequence-of-Use of Controls and Displays

Each participant ranked all of the Pilot's and Copilot's controls and displays in terms of criticality (i.e., the consequence of their failure on mission success). One set of rankings was obtained from each of the following four categories:

1. Pilot controls

2. Pilot displays

3. Copilot controls

4. Copilot displays.

Each set was ranked independently. The coefficient of concordance (ω) was calculated to determine the commonality (level of agreement) among the three participants. Significant agreement was obtained for each category, indicating that the participants generally agreed about the relative criticality of the displays and controls. Mean rankings for each control and display, coefficients of concordance and levels of significance ($\underline{p}$), for each of the four sets are shown in Tables 15 and 16.

Work process charts were developed to determine frequency and sequence of use of all mock-up controls and displays. Separate charts were developed for each personnel position (Pilot and Copilot) and for each of the six test segments. Table 17 displays a work process chart for the Pilot performing a normal en route mission. The numbers in each column indicate the sequence of instrument use for each task. Information for the charts was derived from an analysis of the human performance requirements and from an evaluation of operator performance during testing.

The frequencies of Pilot and Copilot use of controls and displays are shown in Tables 15 and 16. Controls and displays are listed in order of criticality. The first control/display listed was judged by the test participants to be most critical, etc. Frequency data was also ranked to provide a comparison to assessed criticalities. Rank order correlation coefficients were derived to evaluate the relationship between criticalities and frequency of use (i.e., were the components that were judged to be critical also used most frequently?). Significant rank order correlation coefficients were

TABLE 15

Rank Orderings of the Criticality and Frequency of Use of the Pilot's Controls and Displays

	MEAN CRITICALITY RANK	CRITICALITY RANK ORDER	FREQUENCY RANK
DISPLAY			
Airspeed Indicator	2	1	7
Barometric Altimeter	2.3	2	4
Radar Altimeter	4.7	3	4
Vertical Speed	5.3	4	8
EADI	6.7	5.5	6
RPM	6.7	5.5	2
EGT	7.0	7	3
Spoiler	7.3	8	9
Distance to Go	8.7	9	19
Mode Indicator	11.3	16.5	15
MLS	11.3	10.5	15
Flaps	13.3	12	12
Audio Warning	14.7	13	19
Landing Gear	15.0	14.5	11
Fuel Gauge	15.0	14.5	13
Weather Radar	16.0	16.5	18
ADI	16.0	16.5	10
MFD	17.7	18	1
Landing Light	19.3	19	13
Clock	19.7	20	15
	$\omega = .77$ $p \leq .001$		$r = .56$ $p \leq .01$
CONTROL			
RPV Select	2	1	2
Command Guidance	3.7	2	9
Throttle	4	3	5
Joystick	6	4	2
Brakes	6.7	5	6
AFCS	7.3	6	7
Landing Mode	8.3	7	12
Spoiler	8.7	8	11
Flaps	9.0	9.5	16
Landing Gear	9.0	9.5	8
MLS	12.7	11	21
Airspeed Trim	13	12.5	12
Vertical Speed Trim	13	12.5	12
ADI	15	14	21
Destruct	15.7	15	24
EADI	16	16	10
HSI	16.7	17	21
Radar Altimeter	17	18	18
NAV Mode	18.3	19	12
Audio Warning	19.7	20	25
MFD	20.7	21	4
Intercom	21.7	22	1
Weather Radar	23	23.5	18
Push to Talk	23	23.5	25
Landing Light	26	26	17
Headset	26	26	25
Transponder	26	26	20
	$\omega = .83$ $p \leq .001$		$r = .58$ $p \leq .01$

TABLE 16

Rank Orderings of the Criticality and Frequency of Use of the Copilot's Controls and Displays

	MEAN CRITICALITY RANK	CRITICALITY RANK ORDER	FREQUENCY RANK
DISPLAY			
Electrical	3.7	1.5	3
Hydraulic	3.7	1.5	1
Environmental	4.3	3.5	6
Propulsion	4.3	3.5	4
FCS	5.7	5	2
MFD	6.7	6	13
MLS	7	7	7
Flaps	7.3	8	14
PME	10	9.5	5
Wind Direction	10	9.5	9
Weather Radar	10.3	11.5	8
Wind Velocity	10.3	11.5	9
Barometric Pressure	10.7	13	9
Outside Air Temperature	11	14	9
	$\omega = .46$ $p \leq .01$	$r = .62$ $p \leq .02$	
CONTROL			
RPV Select	1.3	1	2
MLS	4	2	3
Electrical	4.3	3	5
AFCS	4.7	4	13
Hydraulic	5.3	5	8
Propulsion	6	6	8
FCS	6.3	7	5
Environmental	7	8	8
NAV Mode	8	9	13
MFD	10	10	11
PME	10.3	11	4
WR	11.3	12	5
Transponder	12.3	13	11
Intercom	14.3	14	1
Headset	14.7	15	13
	$\omega = .79$ $p \leq .001$	$r = .35$ n.s.	

TABLE 17

Sample Work-Process Chart

CONTROLS & DISPLAYS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	FREQUENCY OF USE
Airspeed Ind.	6	6															2	3	5	5
Vertical Speed Ind.							4,11 18									1	3	4	6	7
Baro. Altimeter	2	2					5,12 19						3		7,19				7	10
Radar Altimeter							6,13 20						4		6,18 30				8	8
EADI Display	3	3	4,10 16										6		5,17 29		4		2	11
HSI Controls																				0
HSI Display	5	5	5,11 17			3,7 11							5		4,16 28				4	13
EGT Ind.	7	7					7,14 21								12,24 36	4			10	10
RPM Ind.	8	8					3,10 17								11,23 35	3			9	10
Spoiler Ind.	9	9																2	11	4
Spoiler Cont.																		1		1
Flap Ind.	11																		14	2
Flap Cont.		11																		1
MFD Display					2	2,6 10		2,6 10	2,4,6	2,4,6					9,21 33			6,8		18
MFD Controls					1	1,5,9		1,5,9	1,3,5	1,3,5					8,20 32			5,7		18
Mode Ind.				3												7				2
AFS Controls				2									7			5				3
MLS Controls																				0
MLS Ind.																				0
ADI Display	4	4	3,9 15			4,8 12													3	9
ADI Controls																				0
Weather Radar Disp.																				0
Weather Radar Cont.																				0
Audio Warn Ind.																				0
Audio Warn Reset																				0
Landing-Light Cont.																				0
Landing-Light Disp.																				0
Position Plotter								3,7 11											13	4
Fuel Ind.																				0
Clock c/d								4,8 12												3
Distance-to-Go Ind.																				0
RPV-Select Cont.	1		1,7 13				1,8 15													7
Throttle Cont.							2,9 16								10,22 34	2				0
Cmd.-Guidance Cont.		12																	15	2
Landing-Gear Cont.	10	10															1		12	4
Brake Cont.																				0
Nav/Landing Mode Ind.															3,15 27	6				4
Joystick			2,8 14											2	2,14 26					7
Destruct Cont.																				0
Intercom		1	6,12 18					13			1			1	1,13 25				1	10
Transponder Cont.																8				1
Video Controls				1									1							2
Video Display													2							1
Headset																				0
UHF Radio Cont.																				0
Communication	COP	COP RCF	COP A/C	COP		COP	COP	COP MC	COP	COP	MC COP	COP	COP	A/C	COP	COP	COP	COP	RCF	
Airspeed Trim																				0
Vertical-Speed Trim																				0
Radar-Alt. Cont.																				0
EADI Controls																				0
Time (sec.)	51	86	70	18	5	63	88	76	51	117	29	22	42	14	45	42	21	34	45	
σ_T	15	88	37	12		38	41	35	23	25	8	10	31	1	10	9	13	20	5	

obtained for Pilot controls and displays ($p < .01$), and for the Copilot displays ($p < .02$). The correlation between the Copilot control criticalities and frequency of use was not significant ($p > .10$). The main inconsistencies found were:

For the Pilot:

1. Although the MFD display and controls were frequently used, they were not considered critical to mission success.

2. The distance-to-go indicator was given a mid-range rank in terms of criticality; however, the Pilot never referred to it during the tests.

3. The intercom was the most frequently used control, but it was ranked twenty-second in terms of criticality.

For the Copilot:

1. The intercom was the most frequently used control, but it had the second lowest criticality ranking.

2. The PME control was the fourth most widely used control but was evaluated eleventh in criticality.

HUMAN PERFORMANCE ERRORS

This section describes the major errors that were observed during testing. Error consequences, causes, and recommended solutions/actions are provided for each error.

Vehicle Selection Confusion

Error Description. Both the Pilot's and Copilot's consoles have two RPV-select subpanels (Figures 6 and 7). One set of vehicle selection pushbuttons is on the MFD display-select subpanel. The MFD select buttons allow the operator to select a particular vehicle's data for display. Additional pushbuttons permit selection of specific subsystem data. The second set of vehicle-select pushbuttons control the displayed data on the dedicated instruments in each console. For the Pilot's console, this second control subpanel (RPV command designate) selects the vehicle which is to be manually controlled from the Pilot station. The Pilot's RPV command designate subpanel also selects the vehicle being controlled by the shared subpanel. Fifteen percent of the time, an operator pushed a vehicle select button on the wrong subpanel. This happened more frequently at the Copilot position when an operator attempted to select MFD data for a specific vehicle by pushing the dedicated display-select control.

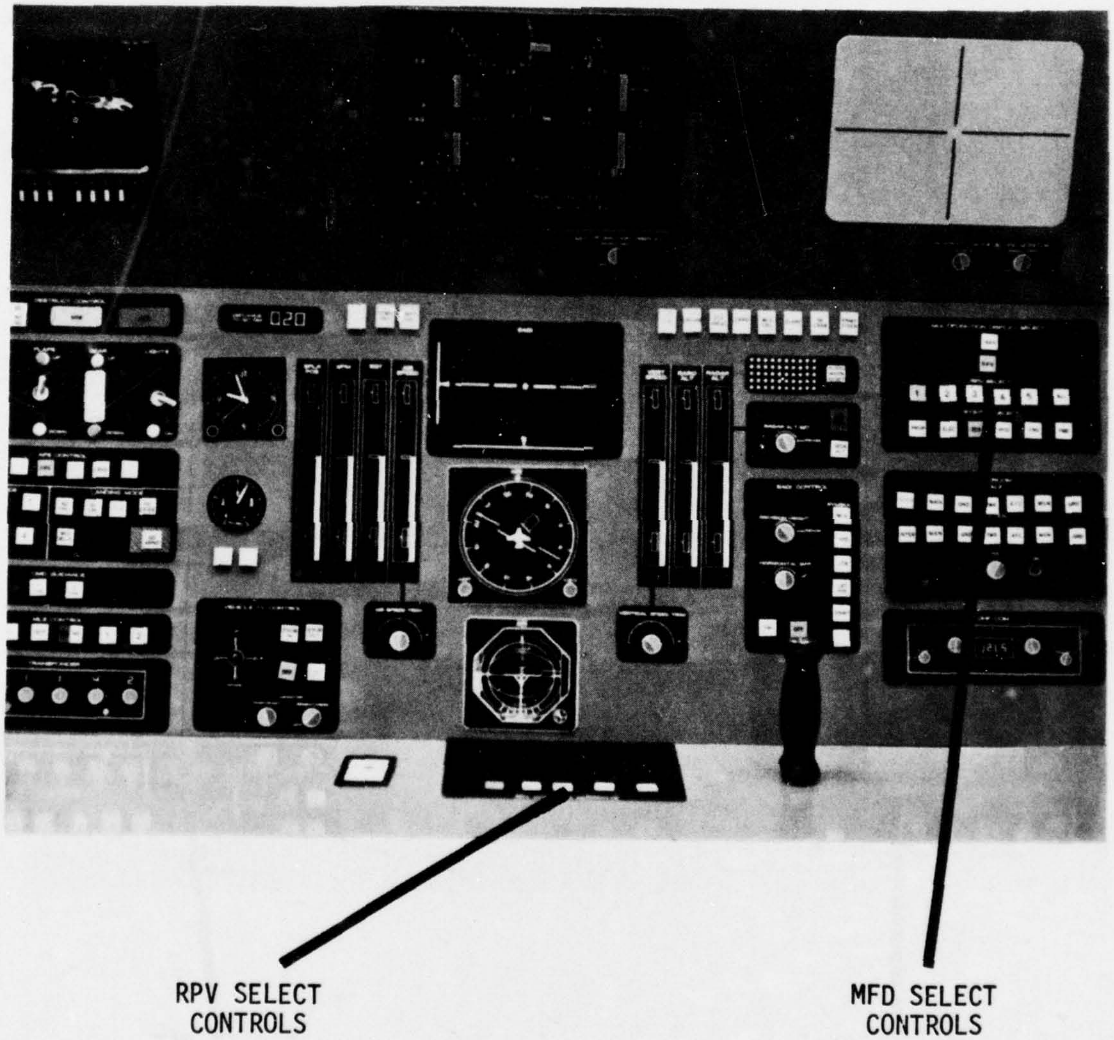
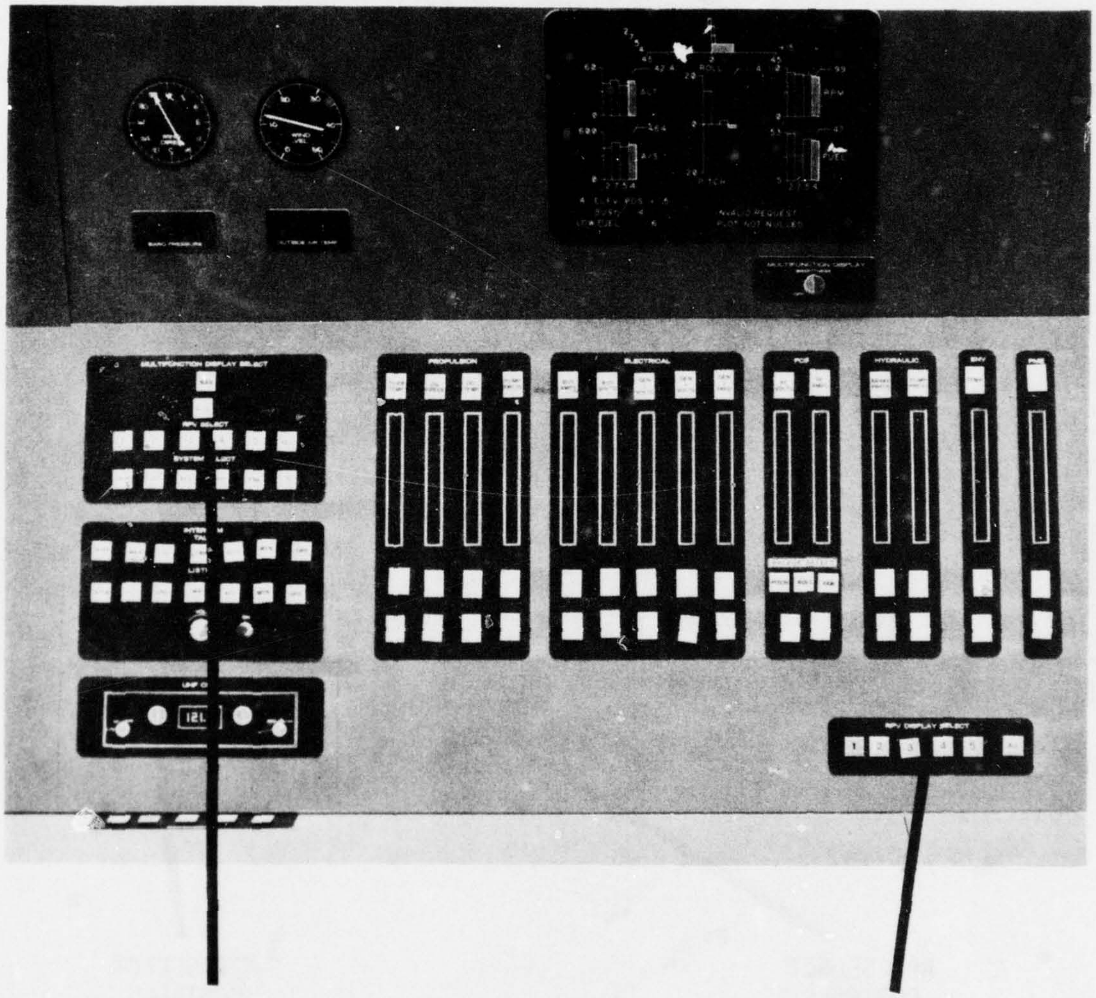


Figure 6. Pilot dual RPV select designate subpanels



MFD SELECT CONTROLS

RPV SELECT CONTROLS

Figure 7. Copilot dual RPV select designate subpanels

Error Consequences. For the Pilot, the consequence of actuating the wrong RPV select panel sends any commands (control actuations) made after actuating the select buttons to the wrong RPV. This act could have catastrophic consequences (e.g., collisions, losing control of a RPV, etc.). If the Copilot detects the Pilot's error, he can reselect the correct RPV. However, if the Copilot fails to detect this error, he will provide the Pilot with incorrect information (e.g., the Copilot might indicate that the generator on RPV #2 was malfunctioning when in fact it was RPV #4 generator that was faltering).

Recommended Solutions. The alternative solutions/actions to eliminate this error are:

1. Locate the MFD control panel closer to the MFD
2. Color code and label the two RPV select panels
3. Add a display next to the RPV select panels that indicates which RPV is being controlled.

The solutions/actions indicated above, along with other solutions, should be evaluated to determine the most cost effective procedure for eliminating this error.

Intercom Panel Confusion

Error Description and Consequences. Each operator's intercom panel includes an illuminated TALK and a LISTEN pushbutton for each station that can be addressed. On several occasions during the HFE test, an operator mistakenly pushed a LISTEN rather than a TALK putton. This error delayed communication until the operator pushed the correct button.

Error Causes. The primary reason for this error was that the design included both TALK and LISTEN buttons for communicating with a single station.

Recommended Solutions. To eliminate this problem, the feasibility of redesigning the communication panel should be analyzed. If feasible, the communication panel should consist of a single bank of illuminated pushbuttons, each button associated with a specific station (tower, ATC, Mission Control, etc.). Since the operators must use their hands to control and monitor multiple RPV's, a footswitch should be provided for the talk function. If a single bank of pushbuttons and a footswitch are incorporated, the advantages will be:

1. There will be fewer buttons to push.
2. The error of pushing the LISTEN rather than the TALK button will be eliminated.
3. A footswitch will reduce requirements for using hands.

Since the communication function is one of the most frequently used subsystems (see Tables 15 and 16), the design and function of this panel should be thoroughly analyzed.

Pilot Overcontrol of Joystick

Error Description and Consequence. Each of the participants tested had a tendency to grasp the joystick throughout the test segments. Figure 8 shows the Pilot actuating the joystick. In an operational setting, this overcontrol would have the effect of continuously adjusting the automatic pilot. It is assumed that during normal conditions, the on-board computer will control the flight parameters of the RPV. The Pilot does not need to readjust these parameters unless some condition arises that necessitates a change.

Error Causes. The primary reason this problem occurred was that all of the operators were used to taking continuous, active control of aircraft, either manned or unmanned.

Recommended Solutions. It is expected that Pilots will be selected to become RPV controllers and that they will have a learned predisposition to hold the joystick continuously. If so, this learned behavior must be trained out. The selected operators should receive training on when, how often, and how to use the joystick.

A slight redesign would also minimize continued handling of the joystick. If the stick were mounted on a pedestal which extends above the horizontal surface, the operator would be less likely to rest his hand on the joystick.

INCOMPATIBILITIES AMONG HUMAN PERFORMANCE AND EQUIPMENT

Task Group Interference

The only task group interference problem observed was in the operator's use of a shared panel. A control panel located between the Pilot and Copilot was shared. During test segment performance, both operators must use some of the controls located on this panel. Figures 9 and 10 illustrate Pilot and Copilot panel use. The controls located on the panel include:

1. Arm and Destruct Mode
2. Flaps, Spoiler, and Landing Gear
3. Automatic Flight Control System
4. Navigation Mode
5. Landing Mode

Figure 8. Pilot actuating the joystick

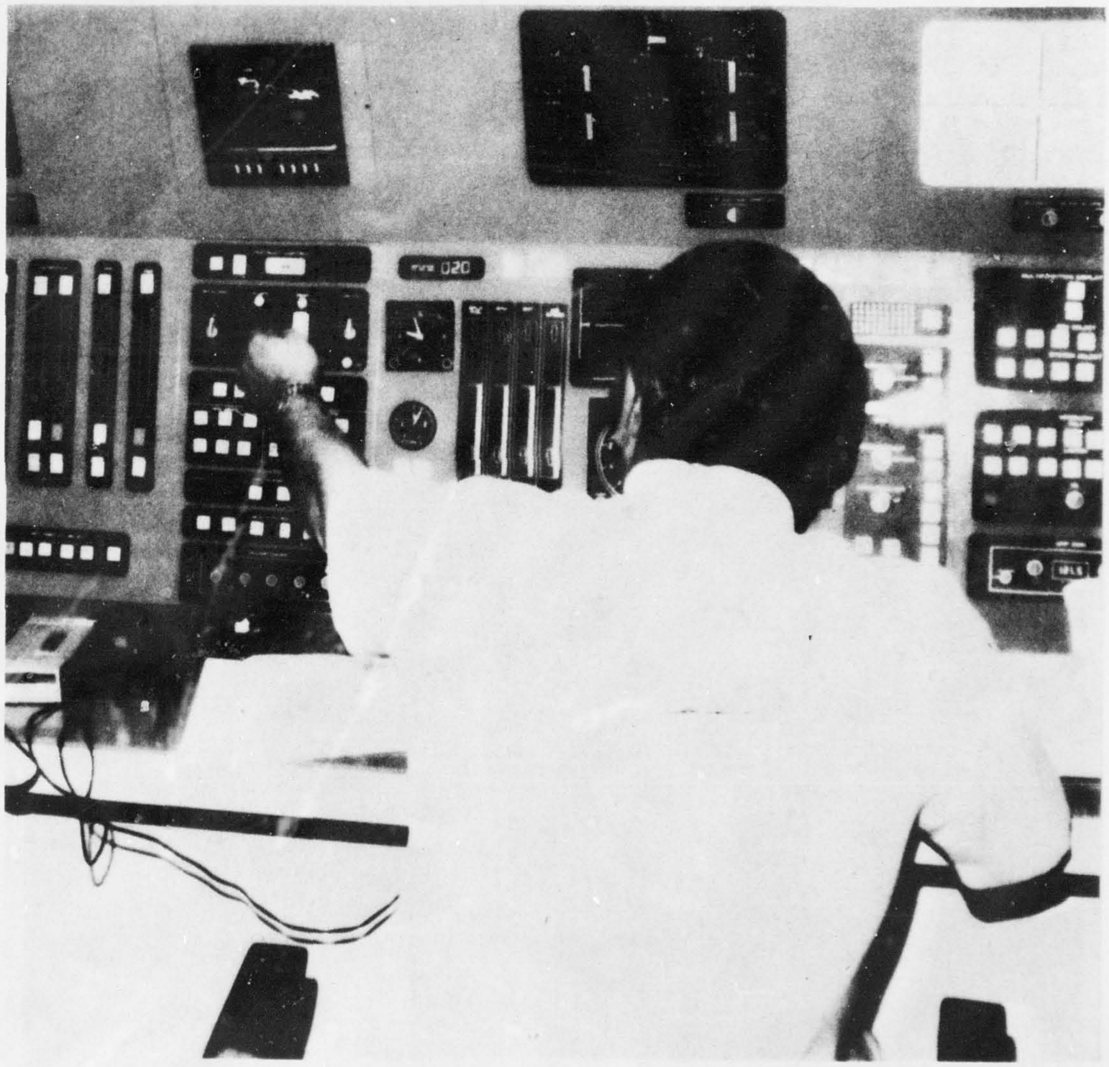


Figure 9. Pilot using shared panel

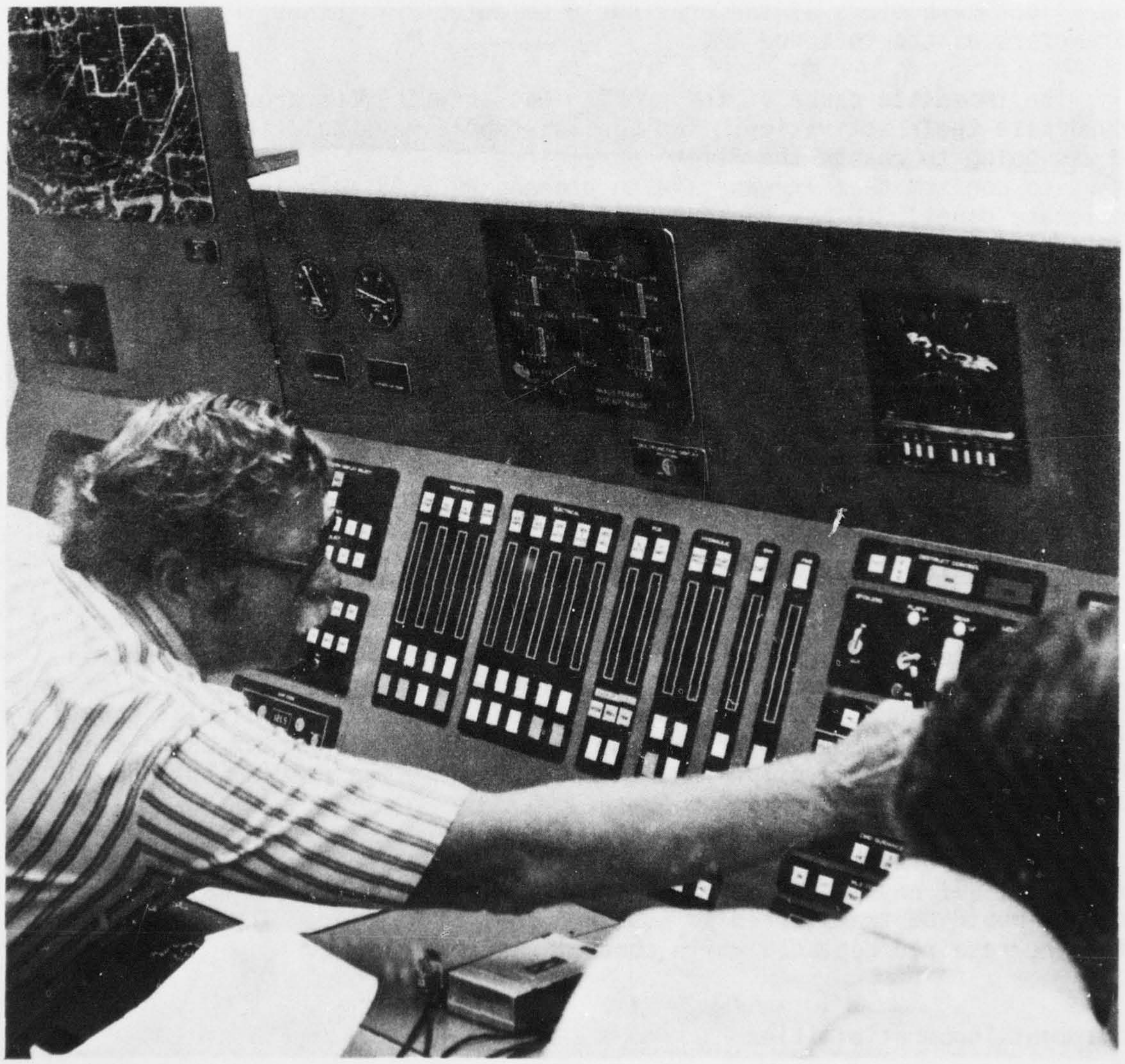


Figure 10. Copilot using shared panel

6. Microwave Landing System

7. Command Guidance

The Pilot's RPV-designate control panel was used to select a particular RPV for manual control. Problems arose when the Copilot attempted to change the flight parameters of a specific RPV before the Pilot had selected that RPV on his designate console. Because of this error, the Copilot altered the flight parameters of the previously selected RPV rather than change the parameters of the intended RPV.

The immediate cause of the problem was that the operators failed to coordinate their activities. The Copilot should have told the Pilot that he was going to change the flight parameters of RPV #2 and waited for the Pilot to confirm that it was safe to proceed (RPV #2 selected on RPV designate panel). Other factors contributing to this error were equipment design and the operators' limited experience with multiple RPV systems.

The shared-panel problem could be eliminated or substantially reduced by any of the following methods:

1. Allocate control to a single operator.

2. Display designated RPV adjacent to or on shared panel.

3. Provide command-designate panel keyboard for shared panel.

4. Train operators to coordinate their activities before using the shared panel.

If the control panel were allocated to a single operator, the shared panel interference problem would be eliminated. If operator loadings prevent assigning the panel to a single operator, an RPV-designate display should be located adjacent to or on the panel to insure that an operator changes only the RPV desired. This display would not eliminate the problem but should markedly reduce its occurrence.

The only other personnel who would use the equipment are the maintenance personnel. If any major component in the RPV control station malfunctioned, control would be transferred to a backup control station. The component would be repaired/replaced while control was transferred.

Equipment Incompatibilities

There is an incompatibility between the Runway and Glideslope Monitor and the On-board Video Display. The on-board video camera is mounted in the nose of the vehicle with a view toward the runway during landing. At the same time, the Runway and Glideslope camera is mounted at the departure end of the runway aimed up the glideslope toward the approaching vehicle. The cameras look directly at each other, so they have completely reversed control/display relationships. In addition, the two cameras have different frames

of reference. The Glideslope camera has an earth-coordinates reference (frame fixed relative to earth) and the on-board camera has a vehicle-coordinates reference (frame relative to RPV).

The incompatibilities between the orientation of the two TV cameras and their respective frames of reference will cause control reversals and hesitations in controlling manually the vehicle's roll during landing operations. Such control reversals can have catastrophic consequences, particularly when the vehicle is at low altitude on the landing approach. It is strongly recommended that one of the two displays be eliminated, particularly since the displayed information is highly redundant.

The on-board video display deserves further analysis, particularly if this display is retained and the runway and glideslope monitor is eliminated. Extensive discussions and research have addressed the question of which frame of reference is most appropriate for aircraft attitude indicators. An extensive review of this research is provided by Johnson and Roscoe (16). To summarize their major findings, an earth-referenced (moving airplane) display generally produces fewer control reversals, particularly if the operator is located in an earth-referenced system such as a fixed-base simulator. For the present vehicle control system, problems of control reversals in vehicle roll can be reduced if the on-board TV display is shown as a moving airplane display, as it would be with an earth stabilized camera. The motion of the displayed vehicle is thus controlled by feedback signals from the camera stabilization system.

Human Performance Problems

A variety of console configuration problems were identified by performing simulated missions with the mock-up. These problems were not easily identifiable by merely discussing or observing console drawings. The mock-up and simulated missions provided a method for identifying the following console configuration problems.

Missing Controls and Displays. During training and simulated missions, the test participants reported that the controls and displays listed next were not included in the console mock-up:

1. Oil quantity indicator
2. Flap position indicator
3. Fuel pressure indicator
4. Destruct arm indicator
5. Prime mission equipment on/off control/display

6. Fuel off arm control/display

7. Fuel off control/display

8. Takeoff-abort control/display

The participants stated that these controls and displays are necessary for successful vehicle operations. The validity of this statement should be assessed, and it should be determined whether the operators need other controls or displays to accomplish their specified human performance requirements.

Unnecessary and Redundant Controls and Displays. In several instances, separate ON and OFF pushbuttons were used where a single ON/OFF button (illuminated in the ON state) would have been appropriate. This was the case for the Vehicle TV, Microwave Landing System (MLS), and Electronic Attitude and Direction Indicator (EADI) control subpanels. In the case of the EADI subpanel, on ON/OFF control is not absolutely required, since there is a series of mode switches (MLS, SPD, etc.), one of which must be on at any time. Therefore, pushing any of these mode switches, thereby illuminating the mode button, could also be used for the ON function.

There is a row of status or mode indicators to the left and right of the EADI display on the Pilot's console. These indicators provide readily accessible flight mode and subsystem failure information. Many of these indicators are identical with display/control indicators on the Automatic Flight Systems (AFS) and Mode Control subpanel, which is located on the shared panel between the Pilot and Copilot. Since the indicators on the AFS and Mode Control subpanel show the same information as the indicators next to the EADI display, the latter indicators should be eliminated. The subsystem failure indicators should be moved to the subsystem control panels. Emergency or non-normal conditions should be indicated with flashing pushbuttons to draw attention to the appropriate control subpanel (36).

Inappropriate Control and Display Placement. From an analysis of the work process charts, behavioral checklists, and information derived from questionnaire and interview data, the following changes are suggested for improving the locations of controls and displays on the Pilot's console.

1. Audio warning -- move out of prominent panel location. There is no associated visual display, and a longer reach distance to the reset button will not be disadvantageous.

2. Mission time clock -- move out of the present location in highly valuable central panel space. Since the Copilot turns the clock on during takeoff, it could be placed left of the weather radar on the upper panel.

3. ADI -- could be moved from the central panel, since it serves as a backup for the EADI. The lower center location would then be available for RPV command designate controls.

4. Multiple vehicle navigation and track control panel -- this panel is located on the horizontal surface directly in front of the pilot. This panel includes a number of pushbuttons for selecting RPV's and for controlling the electronic plotter map. With the exception of the RPV-select buttons, the controls are rarely used. In addition, placing it on the horizontal surface intrudes on the Pilot's available writing space.

The console designer stated that a thorough analysis of the Copilot's station had not been undertaken prior to testing. Much of the Copilot's workload is (1) monitoring the status of multiple vehicles, (2) monitoring subsystem performance, and (3) assisting the Pilot during take-off and landing by calling out checklists and communicating with mission personnel. Most of these activities should involve using the multi-function display (MFD). It is recommended that a thorough analysis be made of the Copilot's station and that relocating the MFD to a more central location be considered.

Difficult Cross-Correlation Between Operator Panels. During testing it was observed that, on occasion, the Copilot would lean over and monitor the Pilot's controls and displays to cross-correlate the data on his instruments with those of the Pilot. Figure 11 shows the Copilot monitoring the Pilot station. No particular system consequence occurred due to this problem. If this cross-correlation of data is required, this problem could be eliminated by either slanting the Pilot's and Copilot's stations so that each could easily view the other station; or, the Copilot could request that the MFD display specific Pilot instruments.

OBSERVED SAFETY HAZARDS

No safety hazards were observed during testing, and no safety hazards were reported in the operators' questionnaires.

IMPACT OF HUMAN PERFORMANCE ON ATTAINING SYSTEM PERFORMANCE GOALS

System Performance Goals

The Compass COPE system requires simultaneous remote control of up to five flight vehicles. Compass COPE is capable of performing four distinct missions: peripheral reconnaissance, battlefield surveillance, ocean surveillance and communications relay. The system performance goals call for:

Figure 11. Copilot monitoring the pilot controls and displays

1. Automatic takeoffs and landings

2. Remote control of vehicles flying to the target, in the target area, and during the return flight

3. Operation in the required high altitude and long endurance (up to thirty hours) missions.

Impact of Problems and Errors

The data from this HFE test indicate that the tasks assigned to the Pilot and Copilot are feasible. However, sufficient problems and errors were detected to indicate that it will be difficult to control the Compass COPE vehicles reliably without modifying or refining the control station. Although the identified console deficiencies could have prevented successful completion of an actual RPV mission, the test sequence was continued beyond the deficiency point by assuming that the missing component would be available. This procedure permitted completion of all scheduled test events.

As described previously, a number of controls and displays are missing, redundant, or inappropriately located; some controls and displays produce errors (e.g., pushing similar but wrong buttons), and at least two incompatible displays (On-board Video Monitor and Glideslope Monitor) are expected to produce control reversals. The anticipated impact of these error-producing design problems on the reliability of the Compass COPE system varies from potentially catastrophic to negligible.

The errors which appear to be most potentially catastrophic for mission accomplishment are the control confusions and control reversals. Control confusion arises with the RPV command-designate and MFD vehicle-select subpanels in which an operator selects a vehicle on one subpanel, intending to use the displays associated with the other subpanel. As described previously, the problem is particularly acute with the Pilot's RPV command-designate subpanel since this selects not only his own vehicle control displays but also the shared panel which can be operated with the Copilot. These confusion errors can send commands to an unintended vehicle with potentially disasterous results, particularly since there is no guarantee that any immediate feedback would prompt the operator to correct his error.

Control reversal errors are expected with the incompatible On-board Video Monitor and the Glideslope Monitor. Although immediate visual feedback is available from either display, the error could be disasterous since the two displays are used simultaneously during the landing phase when the RPV is close to the ground. A reversal in roll control, when the vehicle is within a wing-span distance from the ground, could produce a wing-tip crash.

Many of the inappropriately placed displays will have less impact on overall system reliability, since an operator usually adapts to an awkward arrangement (e.g., audio warning, mission-time clock, ADI). However, the awkward arrangement should be redesigned to eliminate the need to adapt to it. A similar impact on reliability can be expected for some of the redundant controls (e.g., separate ON and OFF buttons); however, the

unnecessary duplication of TALK and LISTEN buttons may cause an operator to miss a communication. This type of error would probably not be catastrophic since the auditory feedback (or lack thereof) is so immediate that it stimulates error correction. Many of the missing controls and displays are expected to be mission-critical (e.g., Takeoff-Abort control/display, fuel pressure indicator, fuel off and fuel off arm control/displays, etc.). Other missing items are probably not mission-critical but, rather, are convenient or expected since they have been included in previous aircraft cockpit designs (e.g., flap position indicator). Some displays which were noted as missing may not require addition to the control panels, since the information could be programmed for display on the MFD.

If Pilots overcontrol the joystick there will probably be little effect on reliability, since immediate visual feedback from the EADI will signal the Pilot that he is making a control input. The lack of cross-referencing between the Pilot and Copilot display panels may have moderate impact on system reliability, since an operator may be too involved to look over to the other panel to obtain potentially critical information.

One major area of human performance could not be assessed during testing, namely, an operator's ability to interpret and use information displayed on the multifunction display (MFD). The impact of human performance with this display should be studied before system design progresses significantly. It is recommended that a human performance test be conducted as soon as dynamic simulation of the Ground Control System (GCS) computer functions is available. This simulation can be conducted on the present mock-up by adding computer-generated CRT displays to simulate MFD information.

Impact Upon System Effectiveness

Error frequencies and performance times from the static mock-up of the experimental prototype of the Ground Control Station will probably have little relationship to the frequencies and times in the final system. Static displays provide no feedback for error correction nor for effective evaluation of display monitoring time. Therefore, system effectiveness was not estimated on the basis of these test data.

Solutions for Improving Human Performance

The majority of recommended solutions to the problems and errors noted in this test involve modifying the operator station's design. Design changes are particularly advantageous over training or personnel selection solutions at this time because (1) in most cases, a redesign should eliminate the problem rather than reduce its occurrence, (2) a design change is a nonrecurring cost, and (3) this early stage of system development encourages redesign, rather than changing a training or personnel selection program which has yet to be defined.

As described previously in the discussion of each problem or error, a redesign is expected to eliminate problems, thereby increasing the probability of successful mission completion. Redesign will be particularly important

for the confusion-producing RPV command-designate subpanels and the shared panel command function, the incompatible Glideslope Monitor and On-board Video Monitor, and some of the missing controls and displays. Since these problems are expected to have potentially catastrophic effects, eliminating the problems will obviously improve system reliability and, thereby, effectiveness. These design recommendations can be implemented in an economical manner since the Compass COPE ground station is still in an early design stage. The resulting improvement in human performance is expected to have a major impact on overall system success.

CONCLUSIONS

Test Findings

The major HFE test findings include the following items:

A. Problems:

1. Some necessary controls and displays were not included
2. Redundant or unnecessary controls and displays were included
3. Several controls and displays were inappropriately placed
4. Operators experienced difficulty cross-referencing with other operator's panel.

B. Performance Errors:

1. Operators used wrong controls in selecting vehicles
2. Pilot over-controlled joystick.

C. Equipment and Task Group Incompatibilities:

1. On-board Video and Glideslope Monitors are incompatible
2. Operators interfered with each other in using the shared subpanel.

Implications for System Performance

The major implications of this HFE test for system performance are that, without design modifications, the multiple RPV's probably cannot be successfully controlled. The control confusion, shared panel task group interference, incompatible displays, and some of the missing controls and displays are expected to produce catastrophic failures. The other problems and errors are expected to reduce system reliability and availability.

Recommended Changes

The following changes are recommended to eliminate sources of error and to improve system reliability and effectiveness:

1. Redesign RPV command-designate subpanels (MFD and RPV select) to eliminate confusion between them.
2. Allocate the present shared panel to a single operator, or design the shared panel to display the selected vehicle.
3. Eliminate one of the incompatible displays (probably the Glideslope Monitor).
4. Use earth-referenced (moving airplane) coordinates in EADI and On-board Video.
5. Include critical missing controls and displays.
6. Eliminate redundant and unnecessary controls and displays.
7. Place controls and displays according to criticality, frequency, and sequence-of-use data.
8. Adjust the angle between operator panels to facilitate cross-referencing.

REPORT OF HUMAN FACTORS TEST OF A SYSTEM IN ADVANCED DEVELOPMENT (COMMUNICATION CONTROL UNIT OF TACFIRE)

This is a sample of an HFE test. The purpose of this test report is to provide guidelines for conducting, analyzing, and reporting on HFE tests for systems in advanced development. The Communication Control Unit (CCU) operator is the subject of the test evaluation. This report is an evaluation of the task requirements, training, selection criteria, and interface equipment pertaining to that position.

This report illustrates the contents and format for a test document prepared according to the specifications of DI-H-1334A.

NOTICE

TACFIRE is currently in the Low Rate Initial Production phase of engineering development. However, for illustrative purposes, it was assumed that this test was conducted at the end of advanced development and prior to any design freeze.

INTRODUCTION

Task Group Identification

This report describes the procedures and results of a human factors engineering (HFE) test of the Communication Control Unit (CCU) operators' task group of the U.S. Army TACFIRE artillery fire direction system. This operator is responsible for establishing and maintaining communication links among the personnel and digital data equipment of TACFIRE units in field artillery battalions and divisions. Field Artillery Cannon Operations/ Fire Direction Assistants (MOS 13E) are the personnel who will be selected to operate the CCU.

CCU Operator Interface Equipment

The CCU operator uses the Communication Interface Equipment (CIE) to (1) establish nets among multiple subscribers and Digital Data Terminals (DDTs), and (2) establish links between selected subscribers. This equipment provides monitoring, switching, control and interface capabilities between various items of TACFIRE communication equipment. The CIE inventory includes the Communication Control Unit (CCU), and the Communication Terminal Box (CTB).

CCU. The CCU is the primary equipment for switching and controlling TACFIRE communications. The CCU provides the capability for establishing wire and radio communication links for voice and digital data. The device utilizes microprocessor capabilities to replace some of the hardware functions of the earlier TACFIRE device (monitoring, patching, and control unit). The CCU, shown in Figure 12, is housed in a 23" high, 31" deep, and 18" wide type C transit case. The total weight of the unit is 150 pounds. The major components of the CCU are a display panel, alphanumeric keyboard, phone jacks, and connectors.

CTB. Before the CCU operator can use the CCU's capabilities, wire lines from radio and wire subscribers must be connected to the Communication Terminal Box (CTB). The CTB is a completely self-contained unit housed in a transportable case 46.75 inches high, 18.13 inches wide and 9 inches deep. The unit weighs 135 pounds. The assembly is normally mounted to the shelter's exterior surface near the door entry. As shown in Figure 13, the CTB has a total of 144 spring-actuated binding posts for connecting field lines. The binding posts and connector pins are wired in parallel. The CTB is a passive unit; no power is required for its operation.

Test Site

The test was conducted between 26 and 31 January 1976, at the ARTADS Field Office, Ft. Sill, Oklahoma. Due to equipment unavailability during normal working hours, test sessions were conducted daily between 0130 and 0700. During testing, the participants were excused from their normal duties;

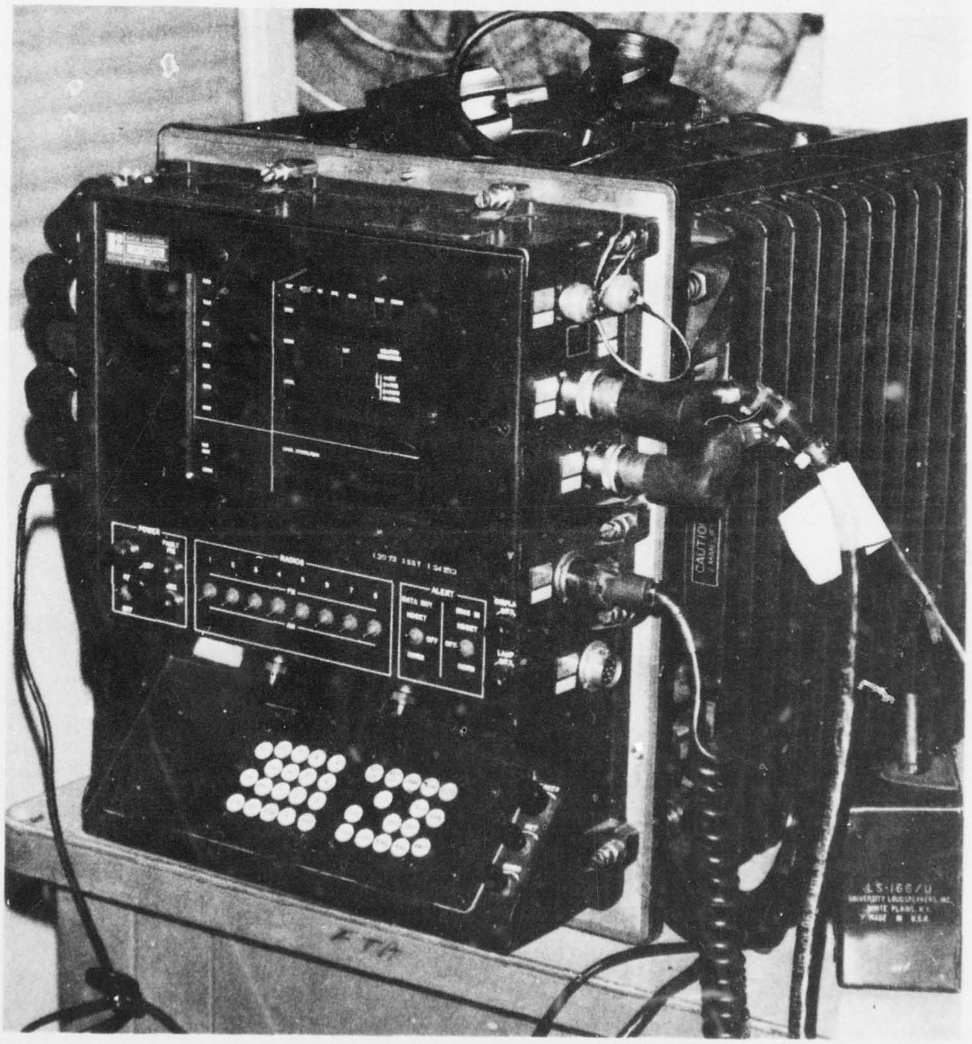


Figure 12. Communication Control Unit

AD-A071 196 PERCEPTRONICS INC WOODLAND HILLS CALIF F/G 5/5

GUIDE FOR OBTAINING AND ANALYZING HUMAN PERFORMANCE DATA IN A M--ETC(U)

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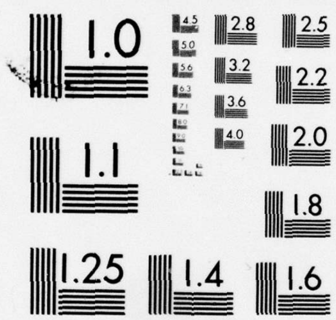
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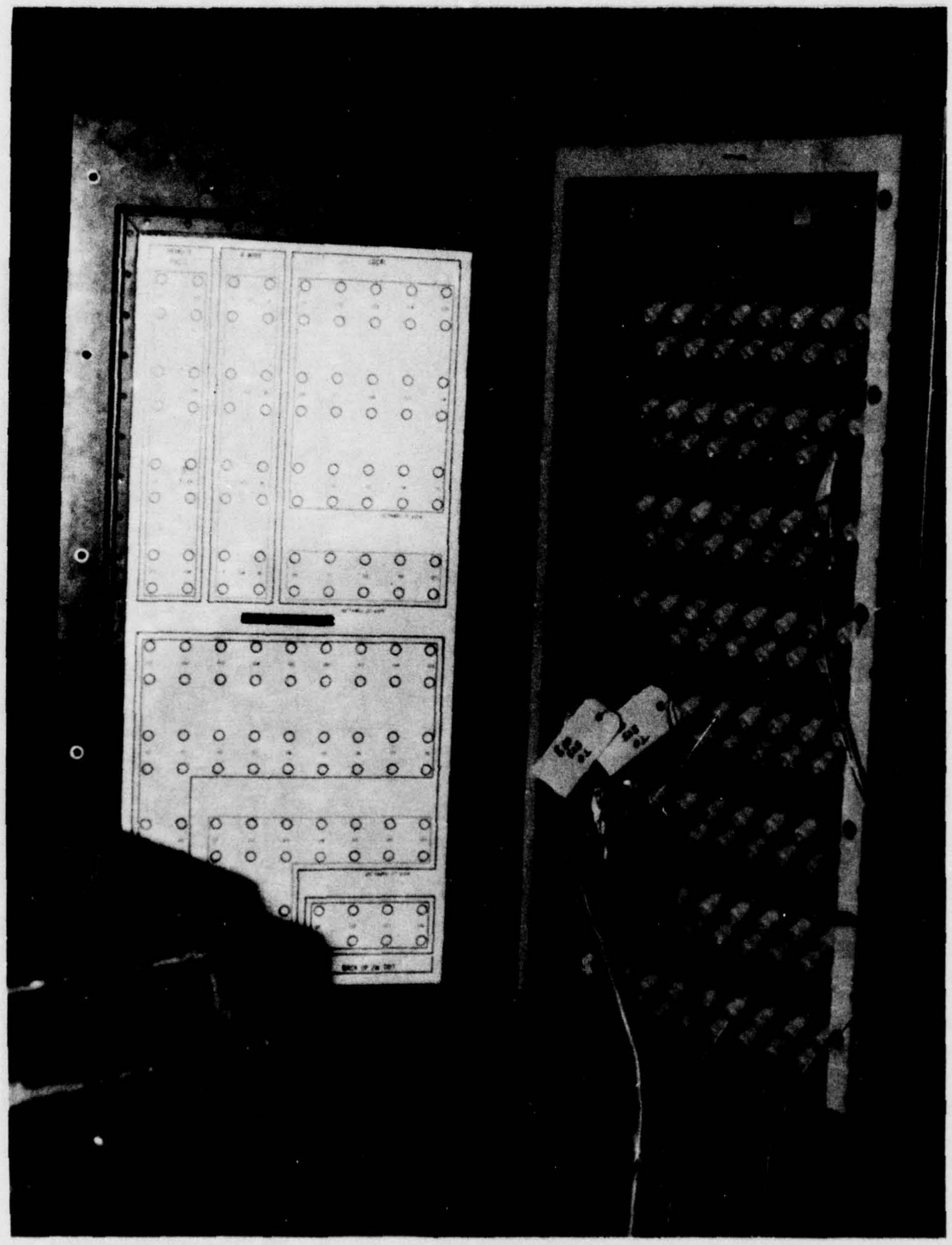

Figure 13. Communication Terminal Box

this test was their only assigned duty. The tests were supervised and conducted by Dr. William H. Crooks and Mr. Barry L. Berson, of Perceptronics, Inc.

TEST PREPARATION

CCU Operator's Task Group

An analysis of the human performance requirements for the CCU operator's task group indicated that the operator was required to perform the following five primary tasks:

1. Connect subscribers to the CTB.
2. Perform equipment start-up procedures.
3. Connect subscribers to nets.
4. Perform CCU operational duties.
5. Perform CCU operational level maintenance.

The human performance analysis gave a complete sequential list of all the tasks, subtasks, and steps in the CCU operator's task group (Table 18).

Human Performance Standards

No human performance standards have been developed for the CCU operator.

Test Environment

The HFE test was conducted in a standard TACFIRE Battalion Electrical Equipment Shelter (Model S-280), which had been cross-sectioned as illustrated in Figure 14. This van was located in a large classroom at the Ft. Sill facility. Therefore, the operator's work station was identical to the operational environment, except that light from the classroom increased the van's normal illumination, and the operator had more seating room than in a normal shelter. To compensate for the latter condition, the operator was not allowed to move his chair back farther than the twenty-five inches normally available.

Components from the TECOM HFE Instrument package were used to measure environmental conditions. Each measure was recorded on the first and last nights of testing. Environmental measures were not recorded more frequently because the test was conducted in an indoor facility and conditions at the test site did not change significantly during the test. The measures were replicated during the last night of testing to verify that the environment

TABLE 18

CCU Operator's Task Group

TASK 1: CONNECT SUBSCRIBERS TO THE COMMUNICATIONS TERMINAL BOX (CTB)

Subtasks

1.1 Connect all radio subscribers listed on the subscriber directory to the CTB

1.2 Connect all local subscribers listed on the subscriber directory to the CTB

1.3 Connect all wire subscribers listed on the subscriber directory to the CTB

TASK 2: PERFORM EQUIPMENT STARTUP PROCEDURES

Subtasks

2.1 Adjust bright control to midrange

2.2 Adjust display bright control to midrange

2.3 Adjust lamp bright control to midrange

2.4 Adjust speaker volume control to midrange

2.5 Adjust switchboard volume control to midrange

2.6 Set alert switches to headset position

2.7 Set power on/off switch to on

2.8 Press keyboard clear key two times or until window is blank

2.9 Set radio am/fm switch to correct position for each radio connected to the CTB

TASK 3: CONNECT SUBSCRIBERS TO NETS INDICATED ON THE NET CONFIGUARATION DATA FORM

Subtasks

3.1 Set up net 1
- a) Press NET key
- b) Press 1 key
- c) Add radio to net--only if radio subscriber is to be placed on net
  - 1) Press radio (RAD) key
  - 2) Press radio number key
  - 3) Press connect (CONN) key
  - 4) Repeat steps 1 through 3 for the remaining radios (up to 3 per net) to be connected to net 1
- d) Add wire to net--only if wire subscriber is to be placed on net
  - 1) Press WIRE key
  - 2) Press wire number key
  - 3) Press connect (CONN) key
  - 4) Repeat steps 1 through 3 for the remaining wire subscribers desired on net 1 (up to 6 per net)
- e) Add digital data terminal (DDT) to net--only if a DDT is to be connected to the net
  - 1) Press DDT key
  - 2) Press DDT number key
  - 3) Press CONN key (only one DDT per net)
- f) Add local (LCL) subscriber to net--only if a local subscriber is to be connected to the net
  - 1) Press LCL key
  - 2) Press LCL number key
  - 3) Press CONN key
  - 4) Repeat steps 1 through 3 for the remaining local subscribers desired on the net (up to twenty per net)

3.2 Set up other nets
- a) Repeat all of the steps in 3.1 for each of the other nets indicated on the net configuration form.

TASK 4: PERFORM CCU OPERATIONAL DUTIES

Subtasks

4.1 Monitor voice/data traffic on net 1
- a) Press Net 1 key
- b) Press monitor (MON) key

4.2 Talk on NET
- a) Press TALK key
- b) Press the PUSH-TO-TALK switch on the headset
- c) Communicate with desired subscriber
- d) Press OFF key to terminate conversation

4.3 Answer net call
- a) Press answer (ANS) key
- b) Press the headset PUSH-TO-TALK switch
- c) Answer call
- d) Press OFF key to terminate conversation

4.4 Link subscribers
- a) Press LINK key
- b) Press the appropriate link number
- c) Input subscriber type
- d) Input subscriber number
- e) Press connect (CONN) key
- f) Repeat steps a to e for each subscriber to be linked

4.5 Disconnect subscribers from link
- a) Press LINK key
- b) Press link number
- c) Press the disconnect (DISC) button three times

4.6 Add/delete subscriber from a Net
- a) Press net number
- b) Press subscriber type
- c) Press subscriber number
- d) Press CONN/DISC depending upon whether the subscriber was to be added or removed from the net

TASK 5: PERFORM OPERATIONAL LEVEL MAINTENANCE ON THE CCU

Subtasks

5.1 Perform wire fault isolation test on selected subscribers
- a) Press keyboard clear (CLR) key two times or until error window is blank
- b) Press LAMP button and monitor CCU display
- c) Press: NET, net number, subscriber number, CONN
- d) Press PUSH-TO-TALK switch to communicate with desired subscriber
- e) Press OFF key to discontinue communication
- f) Repeat steps a through e for each subscriber connected to the CTB

5.2 Perform CCU card checkout on selected cards
- a) Press keyboard clear (CLR) key two times or until error window is blank
- b) Press TEST key
- c) Press subscriber type
- d) Press subscriber number
- e) Press Ring key
- f) Monitor error window. If a 79 appears in the error window, the card is no good; if an 80 appears in the window, the card is OK
- g) Repeat steps a through f for each selected card

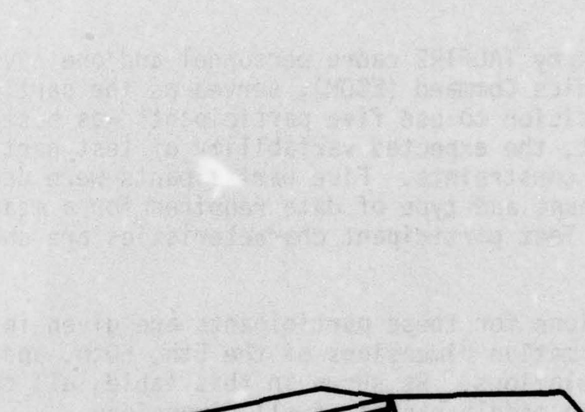

Figure 14. Sectioned TACFIRE shelter

was stable. Table 19 presents the means and standard deviations of the environmental measures. The small standard deviations demonstrate the stability of the environment. Figure 15 shows the measured octave band noise levels.

Test Participants

Five operators, four Army TACFIRE cadre personnel and one civilian from the U.S. Army Electronics Command (ECOM), served as the participants for this HFE test. The decision to use five participants was based on the stage of system development, the expected variability of test participant performance, and budgetary constraints. Five participants were deemed adequate to provide the amount and type of data required for a meaningful analysis of test results. Test participant characteristics are shown in Table 20.

Anthropometric dimensions for these participants are given in Table 21, which also includes normative dimensions of the 5th, 50th, and 95th percentile of military populations. As shown in this table, all test participants were in the low to middle ranges of all dimensions.

Test Participants' Clothing and Personal Equipment

The four military personnel were dressed in fatigues. The civilian operator wore a sport shirt and slacks. During testing, the participants used either a loudspeaker and a hand-held microphone, or a communication headset (CH-182/U). No protective masks were worn, since the operators are expected to work in an environmentally protected shelter.

Participant Training

Each of the four military operators had received eight weeks' training on TACFIRE operation and maintenance procedures approximately three months prior to testing. Of the eight-week period, approximately two days were devoted to CCU operation and maintenance. Each participant received approximately thirty minutes of "hands on" experience. The ECOM civilian had about one-and-a-half years of experience with the CCU. During the time between the participants' initial training and their refresher training, they were not assigned to operate the CCU and received no practice performing CCU operational tasks.

About twenty-four hours prior to testing, the participants were given a one-hour refresher lecture/discussion on CCU operation and maintenance procedures. During this time, all of the tasks that the operators were required to perform during the test were discussed, including the procedures for:

TABLE 19

Environmental Recordings

ENVIRONMENTAL RECORDING	MEAN	STANDARD DEVIATION	N
1. Air Flow			
a. At CCU Keyboard	70 Feet/Minute	7.1	2
b. At CCU Display	190 "	14.1	2
c. Maximum Flow - About 2 ft. Over CCU Operator's Seated Height	925 "	70.7	2
2. Illumination			2
a. At CCU Display Surface	5.7 Ft. Candles	.28	
b. At CCU Keyboard (Lamps Full Bright)	10.8 "	1.1	2
c. Chest Level (In Front of CCU Display)	17.3 "	1.1	
3. Spot Brightness			
a. Single LED Number	.55 Ft. Lamberts	.04	2
b. Display Background	.05 "	.01	2
c. Keyboard (Individual Key)	6.4 "	.57	2
d. Keyboard Surround	1.25 "	.26	2
e. Single Letter on a Key	5.2 "	.43	2
4. Temperature			
a. In Test Shelter	22°C	5.4	10
5. Relative Humidity			
a. In Test Shelter	35%	2.8	10
6. Steady State Noise			
a. Weighting A	68 db	1.4	2
b. Weighting B	69 "	1.1	2
c. Weighting C	72.5 "	.71	2
d. Flat	79.5 "	1.4	2

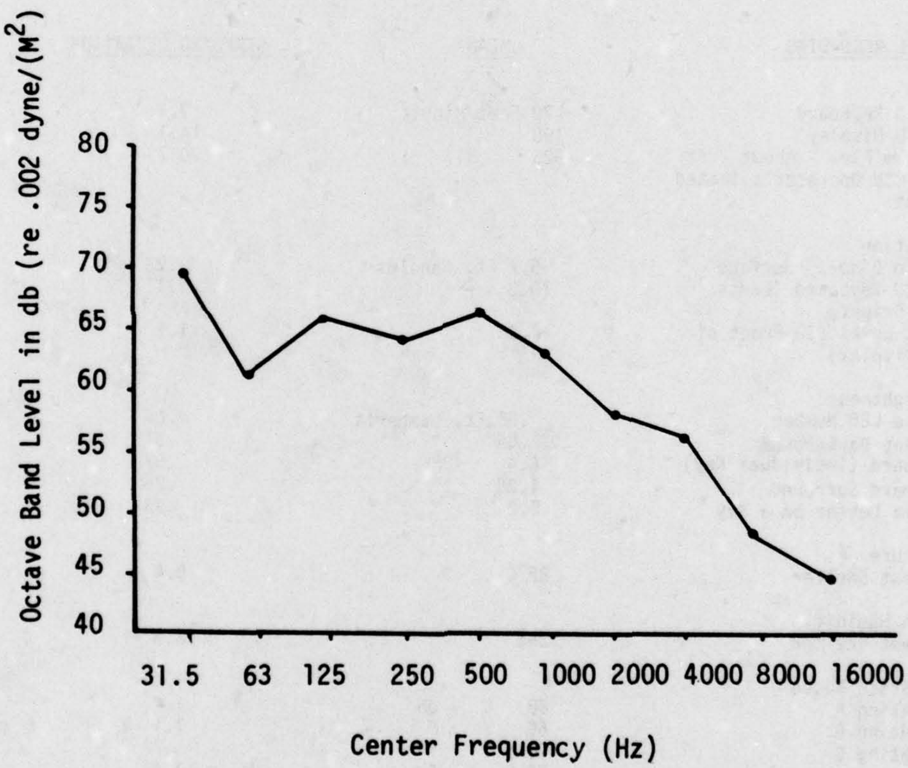

Figure 15. Measured octave band noise

TABLE 20

Test Participant Characteristics

CHARACTERISTIC	PARTICIPANT 1	2	3	4	5
AGE (years)	27	36	28	25	21
WEIGHT (pounds)	195	130	200	130	130
SEX	M	M	M	F	M
SCHOOLING (highest year)	3-College	M.A.	12-HS	B.A.	3-College
YEARS IN SERVICE	5	Civilian	9	1	.75
SERVICE GRADE	E-4	N/A	E-6	E-5	PFC
MONTHS IN GRADE	29	N/A	60	8	9
VISUAL ACUITY	20/20	20/20	20/20	20/20	20/20
DISABILITIES	NONE	NONE	NONE	NONE	NONE
AGCT SCORE	142	N/A	125	123	135
CCU TEST SCORE	80%	93%	79%	74%	97%

TABLE 21

Test Participant Anthropometric Measurements

BODY DIMENSIONS (INCHES)	PARTICIPANTS 1	2	3	4	5	Mean	NORMATIVE DIMENSIONS[a] (PERCENTILE GROUPS) 5%	50%	95%
STANDING HEIGHT	69	70	72	64	70	69	64	67	75.2
SITTING HEIGHT	35.5	32	35	34.5	34.5	34.3	32.5	35.8	38.2
EYE HEIGHT	31.5	28.5	30.5	29	29.5	29.8	28.8	30.9	33.1
ELBOW RESTING HEIGHT	10.5	7	10	9.5	8.5	9.1	7.4	9.5	11.6
HORIZONTAL ARM REACH	32.5	31	34	30	32	31.9	31.1	33.7	36.3
VERTICAL ARM REACH	53	50	53	47	51.5	50.9	51.6	55	59
ELBOW-FINGERTIP REACH	18	18	18.5	16	18.5	17.8	17.3	18.7	20.1
BUTTOCK-HEEL LENGTH	43	42	45	40	45	43	39.8	44.3	48.4

[a] From VanCott and Kinkade, 1972

1. Connecting subscribers to the CTB

2. Setting up nets

3. Using the subscriber directories

4. Performing CCU operations

5. Performing CCU operational maintenance

Immediately following the discussion, each participant received one and one-half hours of practice in performing CCU operation and maintenance tasks.

To assess the test participants' knowledge, a CCU operation and maintenance procedures test was administered to the participants before testing. The test consisted of thirty questions, fifteen taken from the initial CCU training course test, and fifteen new questions derived from the human performance analysis. Test scores ranged from 74 to 97% correct. Test score results, together with the ECOM representative's opinion that the test participants were adequately trained, were used to determine that the participants were ready to begin testing.

Test Equipment

The HFE test used an operational Communication Control Unit and Communication Terminal Box. To simulate TACFIRE subscribers, phones, radios, and another CCU were connected to the CTB with wire lines. After the test operator connected the wire lines to the CTB, he could establish voice communications with the subscribers.

Deviations of Test from Operational Conditions

The major difference between the test and operational conditions was using cadre level personnel as participants. These participants received more training (seven hours of lectures and seven hours of "hands-on" practice) than the operation personnel will recieve (three and three). It is assumed that if personnel with only three hours of lecture and three hours of "hands-on" training were tested, they would have committed more errors.

The following deviations between test and operational conditions also occurred:

1. Brighter lighting in the test shelter

2. More leg room for test participants

3. Fewer personnel in the shelter (during operations as many as four persons will perform their tasks in the shelter).

The first two deviations were caused by using the cross-sectioned van. Both of these deviations were controlled. A black sheet was placed over the

test shelter to reduce the illumination level, and the operator was not allowed to move his chair back farther than the maximum distance allowable under operational conditions. The third deviation was not controlled but it is assumed that it did not significantly affect the test data.

DATA COLLECTION TECHNIQUES

Test Plan

The test plan called for testing each of the five participants on each of the five major CCU operator functions. Five sessions were conducted. During each session, one operator was tested at each of the five major tasks. Each session took about two and one-half to three hours to complete. Participants were randomly assigned to sessions.

Data Collection Methods and Equipment

Behavioral checklists were used to facilitate the process of collecting and recording task group time and error data (see Appendix 2). Checklists were developed for each major operator task. Each checklist contains:

1. A sequential list of all operator tasks and subtasks
2. Descriptions of required operator responses for each task
3. Task success criteria (CCU display indicating satisfactory performance)
4. Columns for recording task response duration, response adequacy (correct/error), and error descriptions

Tasks on the checklists were arranged in the same order that the operator performed them. To evaluate an operator's response on any task, the test director would:

1. Observe the operator's response
2. Observe the CCU display after the response
3. Compare these observations to the response required and the success indicator listed on the checklist.

If the operator performed the task correctly, the test director would place a check (✓) in the appropriate column of the checklist. If the operator erred, the test director would record a brief description of the error in the appropriate column.

A Heathkit digital stopwatch was used to measure operator response times. The stopwatch was started when the test director told the operator to begin and was stopped when the operator indicated that the task was completed. Task response times were recorded on the behavioral checklist.

A Panasonic black and white video tape recorder (VTR) was used to obtain a permanent record of observed task group problems and errors. The VTR was also used to obtain documentary footage of the test.

Test Procedures

This subsection describes the procedures used to collect operator performance data for each of the five tasks.

CTB-Subscriber Connection. For this task segment, the operators were given a preassigned subscriber directory (Table 22). This directory showed the type of circuits to be connected and the name of the subscriber associated with each circuit. The operators were told to connect all of the subscribers listed in the directory. They were also told to work as fast as they could without making errors. In all, thirty-five circuits were connected. After the operators connected the circuits, the test director used a template (Figure 16) to determine if all of the circuits were connected correctly.

Equipment Start Up. In this segment, the operators were instructed to adjust all display, headset, and speaker controls to midrange, to turn on the CCU, and to clear the keyboard. The test director observed and recorded operator performance on the checklist.

Net Set Up. A printed net directory, illustrated in Figure 17, was given to each operator. The entries in the form were assigned by the test director prior to the test session. This directory listed:

1. DDT number, if any, associated with each net
2. The number and name of each radio, local, and wire subscriber to be placed on each net.

The operators were required to set up the nets as listed on the directory. The time required to set up each net was recorded on the checklist. After the nets were set up the test director instructed the operators to display each net. The test director compared the subscribers placed on each net with the subscribers on the checklist. If subscribers had not been placed on the correct net, the test director told the operator to add them to the net. Likewise, if subscribers were placed incorrectly on nets, the subscribers were adjusted accordingly. This adjusting procedure continued until all subscribers were connected correctly. Subscriber placement errors were recorded on the checklist.

TABLE 22

Subscriber Directory

CIRCUIT TYPE	SUBSCRIBER	CIRCUIT TYPE	SUBSCRIBER
Radio		Local	
* 1 FM	Remote Radio 1	* 1	Bn Cdr
* 2 FM	Remote Radio 2	* 2	Mess
3 FM	Remote Radio 3	3	Supply
4 AM	Bdg FSO	4	Motor Pool
* 5 AM	Bn CDR	* 5	Security
6 FM	FSO 1	6	Station 1
7 FM	Batt A	7	Station 2
8 AM	Batt B	8	Station 3
9 FM (Internal)	CF (Bn 1, Bn 2)	9	Station 4
10 FM (Internal)	LBU (LBU Bn)	10	Station 5
		.	
Wire		.	
		.	
* 1	Div/Arty	* 15	Station 6
2	Bn XO	16	Station 7
3	S1	17	Station 8
* 4	S2	18	Station 9
5	S3	19	Station 10
6	S4	20	Station 11
* 7	Comm O.	4 Wire	
* 8	M.A.S.H.	1	
		2	
		3	
		4	

* Subscribers connected to CTB.

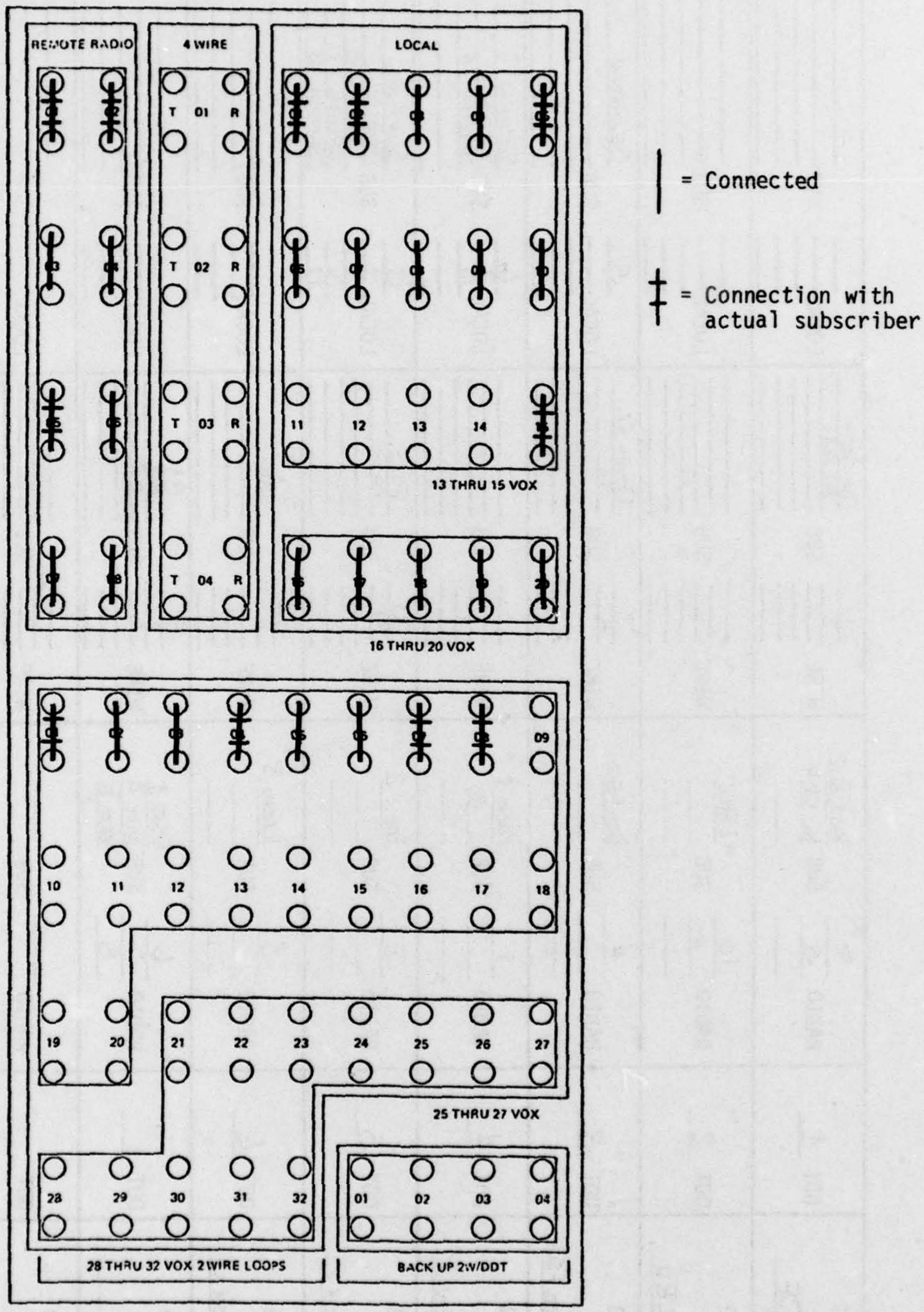

Figure 16. CTB template

Net	DDT	RADIO	SUB	WIRE	SUB	LOCAL	SUB
NET 1 CF	1	9 5	Bn1, Bn2 Bn CDR	1 2	Div Arty Bn XO		
NET 2 LBU	2	10	LBU				
NET 3 Bde FSO	3	4	Bde FSO	7 4	Comm O S2	5	Security
NET 4 Fox 1	4	1	Radio 1			6 7 15	Station 1 Station Station 6
NET 5 Fox 2	5	2	Radio 2	30 31	Fo 5 Fo 6	3 4 8 16 17	Supply Motor Station 3 Station 7 Station 8
NET 6 Fox 3	6	3	Radio 3	32 8	Fo 9 MASH		
NET 7		6 7 8	FSO 1 Batt A Batt B	3 5 6	S1 S3 S4		
NET 8							

Figure 17. CCU net directory

CCU Operations. In this segment the operators were required to perform CCU operational tasks. The segment required the participation of all five participants. One test participant operated the CCU, and the other four participants manned wire, local, and radio lines. Each participant was provided with a script. The script contained a complete list of task operations, indicating the duties each operator was to perform. Each task represented a discrete event. The test director communicated with the operators (via an intercom) and informed them what task was to be performed next. When the test director said, "Task N, proceed", the operators involved would perform their required tasks. Response time and accuracy were recorded on the checklist.

CCU Fault Isolation and Card-Level Maintenance. For this segment the operators were required to perform the following two operational maintenance tasks:

1. CCU Operational Checkout
2. Card Level Maintenance.

For the CCU checkout, the operators were required to connect one wire, one local, and one radio subscriber to different nets and verify that the CCU was sending out a signal. In card level maintenance, the operators performed several keyboard actuations to determine whether the card was functioning. The test director explained the procedures for performing these tasks before testing began. Response times and errors were recorded on the checklist.

Data Reduction Methods

Means and standard deviations were calculated, and reported with the tabulated data. Error rates were reported, as well as a tabular record of errors committed during one test segment. Questionnaire data were summarized in narrative form.

HFE TEST RESULTS

Performance data were recorded for each of the five major tasks. This subsection presents the results of each HFE test separately and summarizes the questionnaire results.

Performance Data

CTB-Subscriber Connection. In this segment the operators connected a total of thirty-five circuits to the CTB (eleven wire, eight radio, and sixteen local circuits). Table 23 presents the total time required for each operator to set up the CTB. On the average, the operators took 13.2 minutes to make all of the required connections. Operator error rate for this task was less than .01 (one error in 135 attempts).

TABLE 23

Data Summary for Test Segment 1 (CTB Set Up)

PARTICIPANT	TIME (MINUTES)	ERRORS
1	11.5	None
2	9.4	None
3	14.2	Left off 1 connection
4	16.6	None
5	14.2	None
TOTAL	65.9	
MEAN	13.2	
STANDARD DEVIATION	2.8	
AVERAGE TIME/CIRCUIT	= 13.2/35	
	= 0.4 MIN/CONNECTION	

Equipment Start Up. In this segment the operators were required to perform all of the tasks required to initialize and clear the CCU. Table 24 gives the total time each operator required to perform the tasks. The mean time to perform equipment start up procedures was 40.1 seconds. No errors were observed.

Net Set Up. In this segment, the operators were required to configure seven nets. The number of subscribers associated with each of the nets is shown in the second column of Table 25. Table 25 also presents the total time required by each operator to configure the nets. The average times required to set up a net and to connect a circuit to a net were 33.6 and 6.5 seconds, respectively. No errors were observed in setting up the nets.

CCU Operations. In this segment the operators were required to perform CCU operational tasks. Table 26 contains operator response times, means, and standard deviations for each task. Tasks which involved similar operations (i.e., set up links, add/delete subscribers to a net, etc.) were grouped together to derive mean times for performing those operations (Table 27). Table 28 lists the errors committed by the test participants while performing this segment.

Descriptions and frequencies of the most prevalent errors are shown in Table 29. The cross-reference and reassignment errors (described in Section 5.) are confounded with the operator disconnect errors; if the operator failed to push the OPR and DISC buttons, he could not reassign the subscriber to his original net. Therefore, these three errors are not reported separately. A single key activation error was scored if one or more keys were activated inappropriately or in the wrong order during any single task.

CCU Fault Isolation and Card Level Maintenance. In this segment the operators were required to perform operation level maintenance on the CCU. The tasks were performed by having the operators press specific sequences of keys on the CCU keyboard to "troubleshoot" the CCU. Table 30 gives the total time each operator required to perform the tasks. The average times required for fault isolation and card checkout were 11.93 and 5.75 seconds, respectively. No errors were observed in this test segment.

In the fault isolation task, the operators were required to place specified subscribers on selected nets and attempt to ring the subscriber. If the subscriber was connected appropriately, the CCU operator would hear a ring when he attempted to ring the subscriber. In the card checkout test, the operators were required to perform a specified sequence of key actuations to determine whether selected cards were operable. The status of the card being tested was displayed to the operator on the error display. If the card was good, an "80" flashed; and if the card was to be replaced, a "79" would flash in the error display window.

TABLE 24

Data Summary for Test Segment 2 (Equipment Start Up)

PARTICIPANT	TIME (MINUTES)	ERRORS
1	56.8	None
2	21.0	None
3	36.5	None
4	32.0	None
5	54.3	None
TOTAL	200.7	
MEAN	40.1	
STANDARD DEVIATION	15.2	

TABLE 25

Data Summary for Test Segment 3 (Net Set Up)

		Performance Time (Seconds)					
		PARTICIPANT					
NET	TOTAL SUBSCRIBERS/NET	1	2	3	4	5	6*
1	5	38.4	14.0	33.3	60.0	31.4	21.4
2	2	14.6	9.0	23.2	14.0	23.0	19.0
3	5	22.9	13.0	35.5	33.0	34.3	17.2
4	5	28.6	34.0	38.6	28.0	31.7	23.7
5	9	51.3	33.0	52.6	47.0	44.8	42.6
6	4	25.6	17.0	37.9	41.0	73.1	29.7
7	6	33.0	18.0	43.7	42.0	46.6	23.6
TOTAL	36	214.4	138	264.8	276	285	177.1
MEAN		30.6	19.7	37.8	39.3	40.7	25.3
STANDARD DEVIATION		11.8	9.9	9.1	14.0	16.5	8.6

OVERALL TIME/NET

MEAN = 33.6 seconds

STANDARD DEVIATION = 14.2 seconds

N = 35

OVERALL TIME/SUBSCRIBER

MEAN = 6.5 seconds

STANDARD DEVIATION = 2.6 seconds

N = 180

*Times recorded for one of the test directors -- not used in calculating average net times or standard deviations.

TABLE 26

Data Summary for Test Segment 4 (CCU Operations)

	Performance Time (Seconds)						
	PARTICIPANT						
TASK	1	2	3	4	5	MEAN	STANDARD DEVIATION
1. VERIFY CONNECTIONS							
a. Radio 1	31.2	23.2	25.7	13.5	37.0	26.1	8.9
b. Radio 5	23.3	48.5	68.8	21.3	28.4	38.0	20.3
c. Wire 4	11.6	61.0	10.7	28.0	33.3	28.9	20.5
d. Wire 7	15.9	39.7	19.6	30.1	15.0	24.1	10.6
e. Wire 8	35.8	39.5	17.2	21.3	20.6	26.9	10.1
f. Wire 1	57.4	122.0	180.0	20.5	180.0	102.0	84.0
g. Local 2	20.7	15.3	42.8	18.1	17.6	23.0	11.3
h. Local 5	24.1	42.0	28.4	21.1	19.1	26.9	9.1
i. Local 15	61.3	40.7	32.9	22.3	43.9	40.2	14.4
TOTAL	281.4	432.0	425.9	185.9	394.9	37.3	25.0
2. VERIFY NETS							
a. Net 1	5.7	4.0	9.0	5.7	5.0	5.9	1.9
b. Net 2	4.6	12.0	10.0	12.7	4.0	8.7	4.1
c. Net 3	13.0	46.5	8.0	10.0	7.0	16.9	16.7
d. Net 4	6.7	10.3	11.0	7.2	8.0	8.6	1.9
e. Net 5	8.6	12.4	12.0	11.7	9.0	10.7	1.8
f. Net 6	5.6	9.4	10.0	5.7	7.0	7.5	2.1
g. Net 7	6.0	15.0	9.4	7.5	7.0	9.0	3.6
TOTAL	50.1	109.6	69.4	60.6	47.0	9.6	3.5
3. 2-WAY LINK	183.4	71.4	438.2	68.2	268.6	206.0	154.5
4. ADD RADIO SUB TO NET	59.4	59.5	85.8	92.8	131.4	85.8	29.7
5. VERIFY NETS							
a. Net 1	9.4	5.9	25.1	5.8	10.1	11.2	8.0
b. Net 4	16.5	7.8	50.2	6.6	16.0	19.4	17.8
TOTAL	25.8	13.6	75.3	12.4	26.1	15.3	13.7
6. 3-WAY LINK	144.3	76.4	203.9	213.6	60.0	139.6	70.7
7. 2-WAY LINK	119.5	44.3	119.2	108.4	30.7	84.4	43.3
8. 2-WAY LINK	34.5	28.3	132.2	99.5	48.2	68.5	45.3
9. ANS RING IN	21.1	30.9	45.9	19.4	20.0	27.5	11.3

(continued)

TASK	PARTICIPANT 1	2	3	4	5	MEAN	STANDARD DEVIATION
10. ADD SUB TO NET	24.2	24.9	33.8	108.4	31.5	42.6	37.1
11. VERIFY NETS							
a. Net 1	6.8	3.9	49.3	9.3	21.4	18.2	18.7
b. Net 3	21.0	9.1	28.5	10.9	10.6	16.0	8.5
TOTAL	27.8	13.0	117.9	20.3	32.0	17.1	13.7
12. MONITOR NET TRAFFIC	7.5	31.9	20.0	18.5	17.9	19.2	8.7
13. DISC LINK	268.9	35.0	23.6	25.9	83.8	87.4	104.3
14. RECONFIGURE NETS							
a. Net 1	14.7	14.7	49.6	29.8	15.3	24.8	15.2
b. Net 2	15.3	23.8	25.1	41.2	24.0	25.9	9.4
c. Net 3	23.6	25.1	28.7	48.0	19.0	28.9	11.2
d. Net 4	35.3	38.2	25.1	63.9	33.7	39.2	14.6
e. Net 5	9.1	46.8	38.2	49.6	18.9	32.5	17.8
f. Net 6	11.0	18.7	25.0	35.7	25.4	23.2	9.1
g. Net 7	23.6	21.5	25.0	31.9	21.0	24.6	4.4
TOTAL	132.6	188.8	216.7	300.1	157.3	28.4	9.7
15. ADD 2 SUBS TO NET 1	28.5	10.6	105.7	22.0	50.3	43.4	37.7
16. VERIFY NETS	5.0	6.4	7.0	6.8	3.2	5.7	1.6
17. 2-WAY LINK	79.7	74.0	136.1	197.4	151.4	127.7	51.7
18. 2-WAY LINK	83.9	19.1	50.1	63.3	45.0	52.3	23.9
19. ADD SUB TO NET	40.3	48.5	50.5	64.2	54.4	51.6	8.8
20. SWITCH DDT FROM 1 NET TO ANOTHER	56.7	33.9	97.1	55.8	43.2	57.3	24.2
21. VERIFY NETS							
a. Net 1	135.0	39.3	28.8	21.2	60.4	56.9	46.1
b. Net 6	25.0	6.1	36.3	24.0	171.0	52.5	67.1
TOTAL	160.0	45.3	65.0	45.3	231.4	54.7	54.3

(continued)

TASK	PARTICIPANT 1	2	3	4	5	MEAN	STANDARD DEVIATION
22. DISC SUB FROM NET	27.5	28.9	25.1	46.6	67.5	39.1	18.0
23. VERIFY CHANGE	8.7	14.3	10.8	8.6	8.0	10.1	2.6
24. 2-WAY LINK	127.0	24.0	208.9	120.9	39.0	104.0	74.9
25. LOCAL DOWN CHANGE CTB							
a. Receive Order	59.4	57.7	60.8	57.6	130.1	73.1	31.9
b. Set Up CTB	52.6	25.7	35.1	30.0	29.0	34.5	10.7
c. Ring Up LCL	35.1	59.7	10.0	14.9	10.6	26.1	21.4
TOTAL	147.1	143.1	105.9	102.5	169.7	44.6	30.1
26. MAKE UP NEW NET	183.2	130.1	129.9	354.3	131.5	185.8	96.9
27. RECONFIGURE NETS							
a. Net 1	11.0	35.3	90.7	33.8	14.9	37.1	31.9
b. Net 2	25.6	15.2	29.8	28.7	30.6	26.0	6.3
c. Net 3	13.9	13.8	16.6	14.1	28.1	17.3	6.2
d. Net 4	26.0	20.6	28.4	31.9	25.4	25.1	6.8
e. Net 5	37.4	39.3	51.6	57.9	48.6	43.2	14.7
f. Net 6	19.4	16.4	20.7	27.1	19.1	20.5	3.6
g. Net 7	23.6	19.9	61.5	46.9	24.0	35.2	18.2
h. Net 8	43.0	36.4	48.3	64.7	26.0	43.7	14.4
TOTAL	183.2	197.0	347.6	345.1	226.8	31.0	20.6

(concluded)

TABLE 27

Summary of CCU Operational Tasks

TASK		OPERATION TIME		
		MEAN	STANDARD DEVIATION	N
1.	Set Up a Link	111.8 Seconds	51.8 Seconds	35
2.	Disconnect a Link	87.4 Seconds	104.3 Seconds	5
3.	Verify a Net	16.7 Seconds	8.1 Seconds	80
4.	Add/Delete a Subscriber From a Net	52.5 Seconds	19.2 Seconds	25
5.	Reconfigure a Net After CCU Power Failure	29.9 Seconds	8.2 Seconds	75
6.	Reallocate DDT to a Different Net	57.3 Seconds	24.2 Seconds	5
7.	Answer a Ring-In From a Subscriber	27.5 Seconds	6.8 Seconds	5
8.	Switch a Subscriber to a New Circuit (Req. Operator to Change Connection in the CTB).	222.8 Seconds	125.4 Seconds	5
9.	Verify a Subscriber is Connected to CCU	37.3 Seconds	25.0 Seconds	45
10.	Establish a New Net	185.6 Seconds	96.9 Seconds	5
11.	Monitor Net Traffic	19.2 Seconds	8.7 Seconds	5

TABLE 28

Error Summary for Test Segment 4

TASK	PARTICIPANT 1	2	3	4	5
1. VERIFY CONNECTIONS	Failure to Actuate KEY ON Headset Inappropriately Placed Key Actuation Errors	No KEY ON Key Actuation Errors OPR DISC Error	No KEY ON Failure to OPR DISC Key Errors	Headset Inappropriately Placed	No KEY ON Key Errors OPR DISC Error Headset Inappropriately Placed
2. VERIFY NETS		Left Subscribers Off Nets Key Errors	Left Subscriber Off A Net		Kept Subscribers Off Nets
3. 2-WAY LINK	Errors in Setting Up Link	Key Errors, OPR DISC Error	Key Errors, OPR DISC Error	Errors in Setting Up Link	Errors in Setting Up Link
4. ADD SUB TO NET	OPR DISC Error		OPR DISC Error	Problem Adding Sub. to Net, OPR DISC Error	OPR DISC Error
5. VERIFY NETS	Sub.Left Off Net		Sub.Left Off Net	Sub.Left Off Net	Sub.Left Off Net
6. 3-WAY LINK		Key Errors	OPR DISC Error	Problem Setting Up Link	Problem Setting Up Link
7. 2-WAY LINK		Key Errors	Problem Setting Up Link Key Errors	Problem Setting Up Link OPR DISC Error	OPR DISC Error
8. 2-WAY LINK	OPR DISC ERROR			Problem Setting Up Link - Lost Subscriber	Problem Setting Up Link - Lost Subscriber
9. ANSWER RING IN				OPR DISC Error	
10. ADD SUB.TO NET	Key Errors		OPR DISC ERROR	Key Errors OPR DISC Error	OPR DISC ERROR
11. VERIFY NETS	Subscribers Missing Key Errors		Subscriber Missing		
12. MONITOR NET TRAFFIC					
13. DISCONNECT LINK	OPR DISC Error	Key Errors		Key Errors	OPR DISC Error
14. RE-ESTABLISH NETS AFTER POWER FAILURE		Key Errors Left Off Subscribers	Left Off Subscribers		Left Off Subscribers
15. ADD 2 SUBSCRIBERS TO A NET	OPR DISC Error		Key Errors	OPR DISC Error	Key Errors

(continued)

TASK	PARTICIPANT 1	2	3	4	5
16. VERIFY NETS					
17. 2-WAY LINK	OPR DISC Error	No KEY ON Key Errors	No KEY ON	Problem Setting Up Link No KEY ON Key Errors	No KEY ON
18. 2-WAY LINK	OPR DISC Error Key Errors	Key Errors			Key Errors
19. ADD SUBSCRIBER TO A NET	Key Errors	Key Errors		Key Errors	
20. SWITCH DDT FROM 1 NET TO ANOTHER	OPR DISC Error	OPR DISC Error	Key Errors OPR DISC Error	OPR DISC Error	OPR DISC Error
21. VERIFY NETS	Missing Subscribers	Missing Subs. Key Errors	Missing Subs. Key Errors	Missing Subs.	Missing Subs.
22. DISCONNECT A SUBSCRIBER FROM A NET		Key Errors			
23. VERIFY NETS					
24. 2-WAY LINK	Key Errors		OPR DISC Error		Key Errors
25. LOCAL DOWN CHANGE CTB		Key Errors			
26. MAKE UP A NEW NET	OPR DISC Error Missing Subscribers		Key Errors	Key Errors Missing Subscribers	
27. RE-ESTABLISH NETS AFTER POWER FAILURE	Key Errors		Left Off 1 Subscriber	Key Errors Left Off 1 Subscriber	

(concluded)

TABLE 29

Frequencies and Descriptions of Major Errors

ERROR DESCRIPTION	FREQUENCY	ERROR RATE
1. KEY-ON Error (Failure to actuate KEY-ON button when attempting to communicate with another CCU)	8 Errors in 10 Attempts	80%
2. Headset Connection Error (Operator connected headset connector into inappropriate jack)	3 Errors in 5 Attempts	60%
3. Opr.-Disc. Error (Operator's failure to actuate the OPERATOR and DISCONNECT keys after a subscriber has terminated communication with the operator)	30 Errors in 90 Attempts	33%
4. Key-Actuation Errors (Operator errors in pressing incorrect keys, incorrect sequencing of key actuations, etc.)	Key Errors Occurred in 38 of the 135 Tasks Performed. 135 = 5 operators X 27 tasks	28%
5. Link Error (Operator difficulty in establishing links, independent of the operator disconnect error)	9 Errors in 35 Attempts	26%

TABLE 30

Data Summary for Test Segment 5
(Fault Isolation and Card Check-Out)

Performance Time (Seconds)

	PARTICIPANT						
TASK	1	2	3	4	5	MEAN	STANDARD DEVIATION
FAULT ISOLATION							
WIRE	17.7	7.0	12.0	13.0	13.4	12.6	3.8
LOCAL	22.1	5.0	9.0	8.0	15.6	11.9	6.9
RADIO	16.8	3.0	9.0	8.0	19.3	11.2	6.7
TOTAL						11.9	5.6
CARD CHECKOUT							
WIRE	9.0	6.0	3.3	5.0	5.1	5.7	2.1
LOCAL	6.7	5.7	4.3	3.7	8.8	4.6	2.9
RADIO	7.0	4.7	4.6	3.7	8.6	5.7	2.0
TOTAL						5.7	1.9

Questionnaire Data

The questionnaire was administered to the operators after they had completed testing. The main findings obtained from the questionnaire are summarized below:

Training and Practice. All of the operators felt that more practice on real equipment and more on-the-job training are required. The operators reported that more "hands-on" experience would have increased their operating efficiency (less time to complete tasks and a lower error rate).

Task Interest. All of the operators found the task of operating the CCU to be interesting. Most respondents felt that an eight-hour duty cycle should be the maximum duty time. The operators were not experienced enough to estimate time-to-fatigue or boredom in operating the CCU.

CCU Operating Procedures. The operators felt that most of the problems they had operating the CCU could have been alleviated with more hands-on experience. No respondent reported a problem in determining when a task was started. The main operating problems reported by the participants included:

1. Updating subscriber forms
2. Determining whether pushbuttons were actuated
3. Establishing and operating nets
4. Establishing links.

Man/Machine Interface. Most of the operators felt that the CCU van was too crowded and that the CCU console should be placed outside of the van. The only interface problem reported was determining whether a pushbutton was actuated. Most of the operators reported they were comfortable, and they all stated that they could easily reach the CCU control panel.

Working Environment. The main item of agreement among operators was that the CCU van was too crowded. The only other item checked by more than one operator was that the noise produced by the hardware in the van interfered with their ability to hear. Other items checked were not internally consistent (one operator reported that it was too dark in the van, while another operator reported that it was too bright, etc.).

End of Test Session Interview

Each operator was interviewed after he had completed his testing. The interviews were conducted to obtain information about the participants' feelings and attitudes toward their training, operational procedures, and testing. The data supplemented the data that had been acquired from questionnaires. The principal findings obtained from the interviews and not reported elsewhere are listed next:

1. All operators stated that more leg room should be provided.

2. All of the operators reported that they needed more adequate writing space.

3. The displayed data were legible, and the operators did not find the displayed information confusing.

4. All operators stated that, without the subscribers' directories, they would have had extreme difficulty in remembering the subscribers' locations.

5. None of the operators were tired when they were tested.

6. All felt that their training was inadequate. They all said that additional hands-on experience/OJT is required. All stated that scenario-based instruction would be extremely useful during training.

HUMAN PERFORMANCE PROBLEMS/ERRORS

This section discusses the major problems and errors observed during the test. Descriptions, frequencies, consequences, causes, and alternative solutions or actions are provided for each error. The errors are discussed in order of importance and rated in terms of their consequences on system performance.

Operator Disconnect Error

Error Description and Frequency. This was one of the most prevalent errors observed. Thirty-three percent of the time (thirty out of ninety occurrences) operators failed to activate the operator (OPR) and disconnect (DISC) keys after terminating conversations with subscribers. A subscriber is automatically placed on the operator circuit when the CCU operator answers the subscriber's ring-in. The CCU operator must manually remove the subscriber from this circuit by activating the OPR and DISC keys before he can place the subscriber on a net or a link.

Error Consequence. The effect of this error is that the subscriber is effectively "lost" from the communcation nets until the CCU operator "finds" the subscriber or until the subscriber rings in again. In the meantime, the subscriber will miss any communications occurring on the net or link to which he should have been connected.

Error Cause. Inappropriate allocation of function was the principal factor in producing this error. The operator is required to press the OPR and DISC buttons to disconnect a subscriber from the operator circuit before

connecting him to a net or link. This task is more appropriately allocated to the machine.

Alternative Solutions or Actions. This error could be eliminated by modifying the software, or reduced by training. Since the CCU is primarily controlled by software, a possible solution to the problem would be controlling the disconnect function through software. The software might work in the following manner. After the subscriber had completed his call, he could ring off. This act could signal the computer to disconnect him from the operator circuit and place him back on the circuit he was on before he called the CCU operator. If the subscriber asked to be placed on another circuit, he would not ring off; the CCU operator would place him onto the other circuit. This act would automatically remove the subscriber from the operator circuit and place him on the desired circuit. Alternative software modifications could be used; however, the impact of such modifications on total system operation should be investigated, since allocating this active disconnect function to software may have other consequences that are not considered here.

A general design philosophy for the CCU should be "active connect and passive disconnect." With this procedure, an operator would have to take positive action to answer or connect a subscriber but not to disconnect him or to place him at his "home" location.

With the present CCU design, training that stresses operator disconnection should reduce the operator disconnect error. However, even the well-practiced operator experienced this problem, so training alone will probably not totally eliminate this error. Increased training will make the operator more aware of the possibility of the error. Therefore, the trained operator would be more likely to look for a "lost" subscriber on the operator circuit, so he could remedy his errors rapidly.

Key Actuation Errors

Error Description and Frequency. In twenty-eight percent of the tasks, the operator made key actuation errors. Key actuation errors included:

1. Pressing an inappropriate key (e.g., an operator was required to actuate the NET key but inadvertently actuated the LINK key)

2. Actuating keys out of sequence

3. Depressing a key without actuating it (i.e., applying a force that is insufficient to actuate the key).

Error Consequences. The consequences of this error ranged from increasing the time required to perform tasks to assigning the subscriber to an undesired net or link or removing him from the desired net or link. If an operator detected the error, he could clear the keyboard and retype the desired command. But, if the operator did not detect the error, subscribers were assigned improperly. Misassigning a subscriber means that he could miss

important communications. This error does not affect the subscribers' ability to communicate with the CCU operator.

Error Causes. Improper key actuation was caused primarily by the following three factors:

1. Inadequate tactile sensory feedback

2. Excessive displacement of the display from the keyboard

3. Close key spacing.

The present CCU keyboard uses rubberized keys. The sensory information provided by depressing the keys was, in some cases, inadequate. To determine whether he had depressed the key, the operator had to look at the status display, which caused an unnecessary delay. The status display, like a typewriter, is outside of the operator's normal viewing area when he is operating the keyboard.

Another keyboard design feature that contributed to error was the close spacing between keys. Center-to-center key spacings varied from .06" to .13". MIL-STD-1472B (36) specifies that the center-to-center spacing should not be less than .635" and minimum key separation should be .25". Closely spaced keys contributed to the operators' errors in depressing adjacent keys incorrectly. Most of these errors were detected and corrected.

Alternative Solutions/Actions. Redesigning the keys so that they provide definite tactual feedback when operated would eliminate the operators' problem of determining whether a key had been actuated. An approach which has been successfully used on other sealed, flat-plate switch keyboards is mounting a relay on a sounding plate so it produces an auditory and tactile signal whenever a key is actuated.

Spacing of the keys farther apart, so they conform to military specifications, could help eliminate the operators' problem of inadvertently actuating inappropriate keys. During testing, it was also observed that the legends on some of the rubberized keys were wearing off. It is recommended that the keys be redesigned to prevent the errors that will probably occur when the labels wear off.

Link Errors

Error Description and Frequency. During CCU operations two or more subscribers can be placed together on a common communication circuit called a link. A link is similar to a net, except that a Digital Data Terminal (DDT) can be included on a net but not on a link. Link errors were observed during twenty-six percent of the trials that involved link operations. Errors observed in setting up links included:

1. Attempting to connect subscribers on the same net before linking them

2. Failing to connect all required subscribers to the link

3. Linking one subscriber at a time and communicating with him before connecting other subscribers, instead of linking all required subscribers and then communicating to them all by talking on the link.

The only procedural difference between establishing nets and links is in pressing the NET or LINK key. The operators' difficulty in establishing links is indicated by the significantly longer time required to set up links (111.8 seconds) as compared with setting up nets (33.6 seconds).

Another error associated with link operations occurred when an operator correctly disconnected all subscribers from the link by pushing the disconnect (DISC) key three times. This procedure places all the previously linked subscribers on the unassigned subscribers net (Net 9). On several occasions, the operators forgot to reassign the subscribers to their original circuits.

Error Consequences. The main consequences of link errors ranged from delays in transmitting desired communications to the possibility of missing critical transmissions. The former results from the excessive time required to set up a link, and the latter because disconnecting the subscriber from a link also removes him from the communication channel he desires.

Error Causes. The main factor that contributed to the operators' difficulty in establishing links was that training did not address the distinction between nets and links. The major factor which contributed to errors in disconnecting links was the equipment design, which requires actively reassigning the subscriber to his original circuit. This is another case where a design philosophy of "active connect and passive disconnect" would eliminate operator errors.

Alternative Solutions/Actions. To reduce the operators' difficulty in establishing links, the distinction between net and link functions and procedures should be covered in training. Procedures for connecting and disconnecting subscribers to a link are nearly identical with the procedures for net circuits. However, if the similarities are not highlighted during training, the operators become confused and behave as though link operations require special procedures.

The link disconnect error can be eliminated by allocating to the equipment the function of reinstating subscribers to their home locations when a link is disconnected. The impact of redesigning the software on total system performance should be investigated before making this change. If the software cannot be restructured, the operators should receive more instruction or on-the-job training (OJT) which highlights the procedure for reconnecting subscribers after disconnecting them from a link.

KEY ON Error

Error Description and Frequency. For one CCU to communicate with another, both operators must activate their respective KEY ON buttons. Eighty percent (8 of 10) of the time, the test operators failed to activate the KEY ON button when connecting a CCU to a net.

Error Consequence. The consequence of this error is that CCUs cannot communicate until both operators actuate their KEY ON buttons. Also, substantial periods of time were required to rectify the error. On the average, it takes much longer to verify connections with a CCU subscriber (102.0 seconds) than it does to verify connections with all other subscribers (30.2 seconds).

Error Causes. Failure to actuate the KEY ON button was caused primarily by the following three features:

1. The CCU operator's training course did not describe the KEY ON function

2. The KEY ON function is used only when connecting another CCU to a net

3. This function was allocated to the operator rather than to the hardware

While the KEY ON function was covered in the pre-test refresher training, it was not covered in the participants' previous training. This, together with the fact that the KEY ON function is seldom used, contributed to the operator's forgetting to actuate the KEY ON button. The immediate cause of the error was that the CCU operator had to actuate the KEY ON button before communicating with another CCU, but he could connect any other subscriber to a net simply by pushing the device's name button (e.g., the RAD [radio] button followed by the CONN [connect] button).

Alternative Solutions/Actions. Allocating the KEY ON function to software will eliminate this error. As with other recommended software changes, the impact of redesigning the software to accomplish this function should be investigated to determine its overall effect on total system performance. If it is determined that allocating the function to software is not feasible, increased operator training and job aids should be developed to reduce the frequency of this error. For example, the form used to record subscriber locations could include a written reminder to the operator to be sure to acutate the KEY ON button when connecting a CCU to a net.

Headset Connection Error

Error Description and Frequency. Two headset connections have been provided on the CCU. Plugging the headset into the upper connector allows the operator to communicate with the nets configured by the CCU. Connecting it to the lower jack gives the operator the same capability, plus the option

of answering calls from local subscribers. Sixty percent of the time, the test operators plugged the headset connections into the wrong (upper) jack.

Error Consequence. The result of this error was that the operators could not communicate with subscribers until they connected the headset to the lower jack.

Error Causes. The primary cause of this error was that the headset jacks were not labeled. Also, most operators were unaware of the differences between the two headset connectors, which added to their confusion.

Alternative Solutions/Actions. Placing a written description of its functions next to each jack should nearly eliminate the error, and it would aid the operator in correcting any errors that do occur. The test directors were unable to determine whether two jacks were required. It was assumed that since two jacks were installed, both are required. If it turns out that one jack is sufficient, the problem could be solved by removing the unneeded jack.

INCOMPATIBILITIES AMONG HUMAN PERFORMANCE AND EQUIPMENT

Task Group Interference

The only task group interference observed during the test was between the CCU and ACC operators. The ACC operator station is immediately adjacent to and in front of the CCU station. For the CCU operator either to reach or leave his station, the ACC operator has to stand up and move his chair. The CCU operator's personal space (elbow room) is limited by the van configuration and by the presence of the ACC operator. The CCU operator does not have sufficient space to record information or to stretch out. Figures 18, 19, and 20 illustrate task group interference and show the inadequate space provided for recording data. Figure 18 illustrates the relative positions of the ACC and CCU operators. The actual van floor space is indicated by the striped floor area in the figure. As may be seen in Figures 19 and 20, the CCU operator does not have sufficient space for a work/writing platform. Figure 19 shows a CCU operator seated in front of the CCU. In a normal van the back of his chair would butt up against an equipment rack. Figure 20 shows the CCU and its associated connections.

Equipment Incompatibilities

No equipment incompatibilities were observed.

OBSERVED SAFETY HAZARDS

No safety hazards were observed during testing.

Figure 18. CCU and ACC operators sitting in front of their respective stations

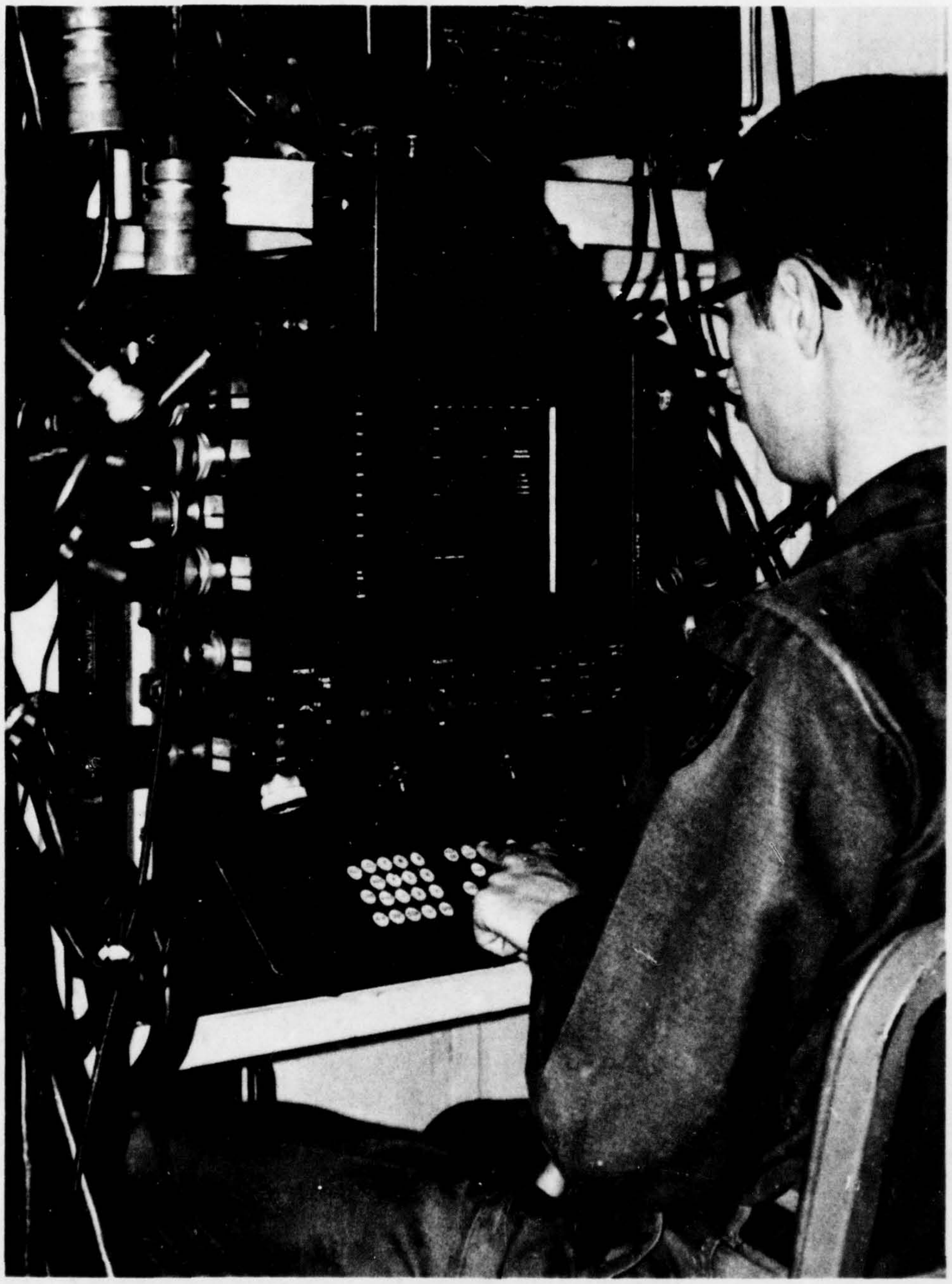

Figure 19. Operator seated in front of the CCU

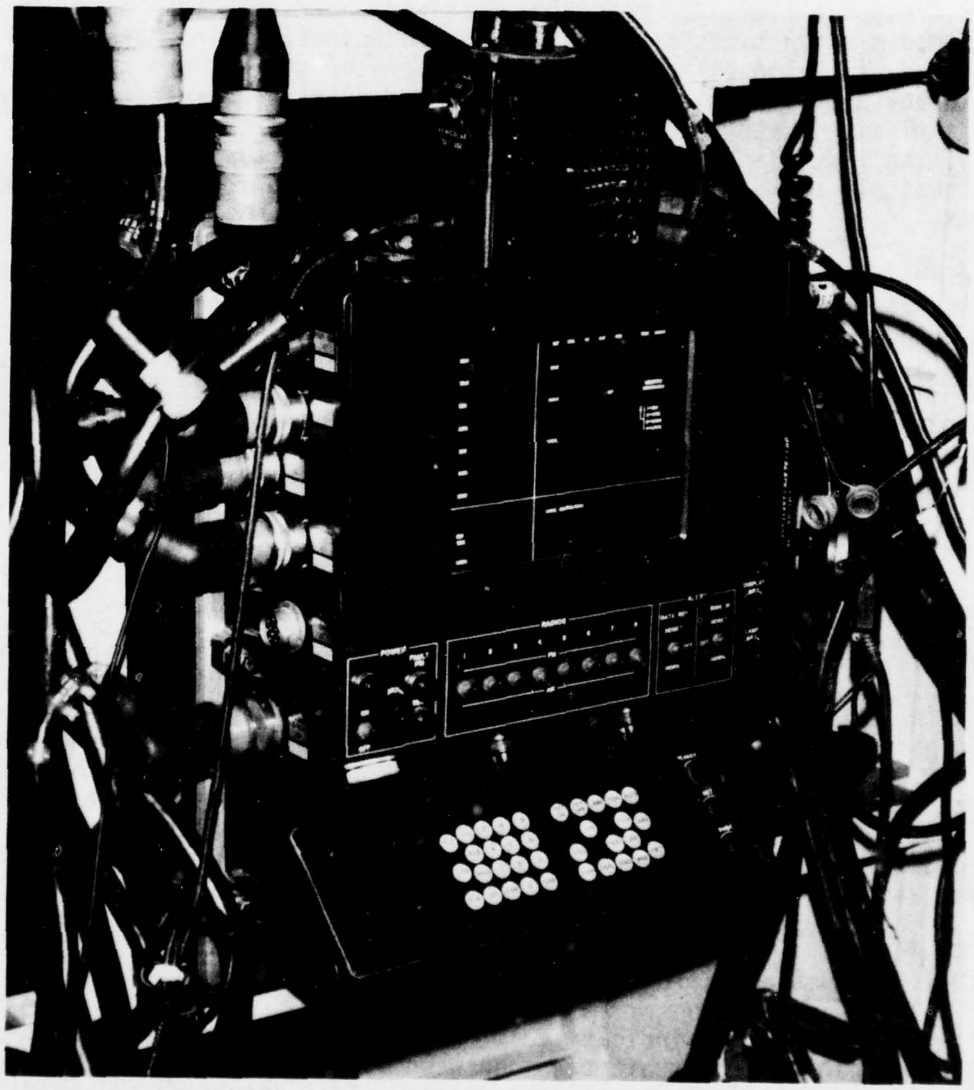

Figure 20. CCU and its associated connections

IMPACT OF HUMAN PERFORMANCE ON ATTAINMENT OF SYSTEM PERFORMANCE GOALS

System Performance Goals

TACFIRE system performance standards are specified in terms of the system's response times to complete 26 field artillery missions. These mission response times include data processing and transmission times; however, response times for personnel tasks are not included. In particular, the defined mission times assume that all communication lines are pre-established, implying either that the CCU operator's tasks are completed prior to any artillery mission or that the CCU operator completes his tasks during a mission, with no errors, in an infinitely short time period. Clearly, the last alternative is unreasonable. It is also unreasonable to assume that all communication links will be in place before all possible missions.

In the absence of defined CCU operator performance standards, a baseline task was selected to demonstrate how human performance impacts on system response times. The selected baseline task was "set up a net", identified as subtasks 3.1 and 3.2 in Table 18. This subtask was completed in a minimally short time (mean = 33.6 seconds/net), the variance among test participants was low (standard deviation = 14.2 seconds/net), and no errors were observed in setting up the nets. Therefore, this subtask represented the minimum time and error rate that could be expected for most CCU operations.

Human Performance Standards

All human performance tasks identified for the CCU operator have been shown by this HFE test to be feasible. However, the performance standards for TACFIRE explicitly exclude the human performance component. Thus, it was not possible to assess whether any human performance standards can be met. As indicated in the following paragraphs, human performance has been compared with mission times assumed for TACFIRE, even though those mission times specifically excluded the human performance component. According to this comparison, human performance can be expected to exceed significantly the time assumed for mission accomplishment.

Impact of Problems and Errors

These HFE test data indicate that a CCU operator can be expected to establish the initial communications between subscribers of a TACFIRE unit in a timely and relatively error-free manner. Test operators attached the subscriber lines to the CTB, initialized and cleared the CCU, and established all initial communication nets with only one error in more than 400 operations. However, a CCU operator can be expected to make a considerable number of errors during CCU operations when subscribers are using the communication nets. These errors range from minor key actuation errors, which are detected and corrected immediately, to major ommissions (OPR DISC and KEY ON errors)

which produce extensive delays and cause subscribers to miss communications. On the other hand, operator maintenance can be accomplished in a relatively short time with few errors.

Operators detected most of the errors observed during CCU operations (link establishment and key actuation errors) and corrected them after some delay. In some cases, such as activation of an incorrect key, the CCU operator rapidly discovered the error and corrected it with little disruption of his task. Other errors, such as verifying connection with each link subscriber individually, rather than verifying all subscribers simultaneously, delayed the task excessively but did not prevent its completion.

However, several error-producing problems are expected to decrease the reliability and availability of communications through the CCU. In particular, the operator disconnect (OPR DISC) error, which occurred 33% of the time, can be expected to reduce the reliability of communications if a subscriber must speak to (ring in) the CCU operator. In this case, the CCU operator must remember to disconnect the subscriber from the Operator Circuit. There is no feedback to tell the CCU operator if he has failed to push the OPR DISC keys. Long delays can be expected in restoring a subscriber to an intended circuit. This error will have a noticeable impact, not only in terms of its consequence but also in terms of its frequency of occurrence. After all CCU subscribers have been initially connected and the subscribers begin to request a variety of changes in the configurations of communication nets and links from the CCU operator, he must push OPR DISC frequently. This high task performance rate, plus the high rate of errors (33%) when the task is performed, will create many opportunities for the error to occur. These errors will reduce system reliability, but they will also make the operator more aware of their likelihood, thereby offsetting some of the negative impact on reliability.

The KEY ON error is not expected to occur frequently; thus, an operator will not learn as rapidly to guard against its occurrence so quickly. As a result, the KEY ON error can be expected to have a noticeable impact on system availability since there may be long delays in establishing communication among CCU's in several TACFIRE units.

Impact Upon System Effectiveness

Since the CCU operator's human performance time goals have not been specified, the impact of the operator's performance times and error frequencies on overall system effectiveness must be estimated from his test performance with identified missions.

The performance requirements for TACFIRE's automated data systems are described in terms of mission response times under assumed conditions. One such mission would be to issue a firing order to a particular artillery battery in response to a firing request from a forward observer. This mission can be assumed to occur within 10 seconds. In this case, the mission response time is measured from the time the forward observer pushes the "TRANSMIT" button on his message-entry device until the firing order is displayed on

the battery message printer. The mission time includes data transmission, computer calculations, active acceptance of the computed firing order by the Fire Direction Officer (FDO), and the specified probability of the system being down for maintenance. The mission conditions also assume that all required communication circuits have been pre-established. The specified mission response time does not include the time required for the forward observer to input the target data into his message-entry device, any time required by the ACC operator to select alternative firing orders, or any time required by the battery personnel to implement the firing order. These latter performance times can be expected to be several times longer than the mission time itself, since the previously identified baseline task (setting up a net) requires a mean performance time of 33.6 seconds.

Given this baseline task as a representative example of the time required for the CCU operator to establish a communication circuit, it can be seen that the sample mission response time would be increased 340%, from 10 seconds to 43.6 seconds, if the mission had been defined to include any time required to establish communications. Obviously, some communications circuits would have been set up by the time any artillery firing order would be required. Therefore, a more complete assessment of mission response time would include some estimate of the probability that the required communication circuit is not yet established. For the purpose of illustration, assume this probability to be 10%. Thus the estimated response time would be calculated as:

Response time = Data transmission and calculation time
+ communication set-up time
= 10 sec. + (.10) (33.6 sec.)
= 10 sec. + 3.4 sec.
= 13.4 seconds

Thus, if nets are assumed to be established during 90% of the missions, a 34% increase in mission response time is found, compared to conditions of 100% pre-established nets.

If the mission could not be accomplished over the standard nets and a link had to be established, the mission response time would become considerably longer. The average time required by the test subjects to set up a link was 112 seconds. This task includes not only connecting the subscribers, but also requires answering a ring-in from a subscriber requesting that the link be established. The task of establishing a link is also likely to include the OPR DISC error (33% of the time) where the operator fails to push the OPR DISC buttons after answering the ring thus keeping the subscriber on the operator circuit. Thus the link set-up time can be analyzed as a combination of times as follows:

Link set up = connect circuit
(time)
+ answer ring
+ (correct OPR DISC error) x (prob. of error)

The task of establishing a link requires 230% more time-112 seconds as

compared to 34 seconds-than the highly similar task of establishing a net. Thus, if the firing order must be sent over a link which has not yet been established, the mission response time would increase from the original 10 seconds to 122 seconds.

When a TACFIRE mission includes communication between two fire direction centers, a single net can be established, with the CCU from the second fire direction center considered as a subscriber to the first CCU. For example, such a configuration would occur if one battalion TACFIRE computer was inoperative and a second battalion TACFIRE computer operated as the Lateral Back-Up (LBU). The mission response time for receiving the firing request from the forward observer and issuing a firing order can be assumed to be 14 seconds, if all communication nets are pre-established. As illustrated earlier, if the communication nets are assumed to be established 90% of the time, the response time for the present mission increases from 14 seconds to 17.4 seconds. However, in the present case, there is a high probability that the CCU operator will fail to press the KEY ON buttons, failing to establish communication between the two CCU's. The test participants failed to press the KEY ON buttons in 80% of the required occasions. The time required by the operator to identify and correct the KEY ON error will vary considerably, depending primarily on the operator's training and experience. For the purpose of the HFE test, timing was continued until the error was corrected or until 180 seconds had elapsed. Given this restriction, the average time to verify a connection with another CCU was 102 seconds, as compared with 29 seconds to verify connections with all other types of subscribers. Given these data, the time required to complete the mission of generating a firing order and transmitting it between two TACFIRE computer centers may be calculated as follows:

Mission response time

$$\begin{aligned} &= T_C + P(\overline{C})\,[(T_C) + P\,(E)\,(T_E)] \\ &= 14 \text{ seconds} + (.1)\,[(33.6 \text{ sec.}) + (.8)\,(102 \text{ sec.})] \\ &= 14 \text{ seconds} + 11.5 \text{ seconds} \\ &= 25.5 \text{ seconds} \end{aligned}$$

Where

T_T = Data Transmission and Calculation time

T_C = Communication set-up time

T_E = Error-correction time

$P(\overline{C})$ = Probability communications will NOT be established

$P(E)$ = Probability of KEY ON error

Assuming that communication nets would be pre-established 90% of the time, and given the restricted time allowed for detecting the KEY ON error in the HFE test, the mission response time is increased by 82%, from 14 seconds to 25.5 seconds. If the error-correction time had not been

arbitrarily restricted to 180 seconds during testing, a significantly larger increase in mission response time would be found.

This HFE test has demonstrated that the time required by the CCU operator to perform his normal duties contributes significantly to the mission response times defined for the TACFIRE system. However, it must be stressed that the TACFIRE mission response time performance requirements were expressly defined to exclude human performance, including message entry, selection of alternative computer-generated firing directives, responding to computer-printed orders, etc. Given this limited definition of required response times, the task of establishing communication nets was shown to provide a baseline for comparing other CCU operator tasks. This test has demonstrated that operator errors, such as failing to push the correct buttons, can increase a task performance time as much as 80% and that a poorly-understood task, such as connecting a link, can increase the task time by 230% as compared with the similar baseline task.

Solutions for Improving Human Performance

Design changes have been recommended for the error-producing problems noted in the task, since a one-time investment in redesign should eliminate the errors, whereas recurring training costs would be expected to reduce but not necessarily eliminate the errors. In particular, software changes are recommended to eliminate the OPR DISC and KEY ON errors. Key redesign, such as adding a sounding relay, is recommended to eliminate key actuation errors. Wider key spacing is recommended to eliminate simultaneous key pressing.

Increased training is recommended to reduce the long time delays noted in the CCU operations. These latter tasks included errors which could be eliminated by the recommended design changes. But the task performances also included enough hesitations to suggest that thorough training, particularly, "hands-on" training with task scenarios, will dramatically improve performance times. The observed time delays will also be reduced with increasing on-the-job training as a new CCU operator becomes familiar with TACFIRE team procedures.

CONCLUSIONS

Test Findings

The major HFE test findings are summarized below:

a. Problems:

1. Depressing the keys provided the operator with inadequate sensory feedback to determine whether the key had, in fact, been actuated.

2. The center-to-center spacing of the keys was closer than MIL-STD-1472B (36), specifies.

3. The operator did not have sufficient space or a work surface to record required information.

4. Headset jacks and connections were not labeled causing operators to connect the headsets to an inappropriate jack.

5. The keyboard is designed for initial establishment of nets; it is not appropriately designed for performing CCU tasks during operations.

b. Performance errors occurred during the following tasks:

1. Disconnecting subscribers from the CCU operator circuit (Operator disconnect error).

2. Establishing nets.

3. Setting up links.

4. Disconnecting links.

5. Attempting to establish communication with another CCU (KEY ON error).

c. Equipment and task group incompatibilities:

1. The CCU operator can not get to or leave his work station without interfering with the ACC operator.

Implications for System Performance

The results of this HFE test demonstrate that a trained CCU operator can rapidly and accurately attach the communication wires to the CTB, establish the initial net and link connections among subscribers, and perform the maintenance checks on the CCU circuits. However, the test demonstrated that long time delays and many errors can be expected to occur when the CCU is used as a communications switchboard and the CCU operator is required to reconfigure nets and links in response to subscriber requests. During these latter CCU operations, the operator's errors and time delays will reduce the reliability and availability of TACFIRE communications, particularly when a CCU operator first joins a TACFIRE team. The recommended design changes are expected to reduce the operator's errors significantly, and the recommended training improvements will improve his performance times.

Recommended Changes

The following changes are recommended to eliminate sources of error and to improve overall system reliability and effectiveness:

1. Allocate to software the tasks of (a) disconnecting subscribers from the operator's circuit, and (b) activating the "KEY ON" function before communicating with another CCU.

2. Expand the training program to include hands-on practice in performing net and link tasks. Use scenarios similar to those used in testing to insure that trainees can perform all required tasks.

3. Redesign the keys so that they provide definite actuation feedback.

4. Label the communication headset jacks to reduce the probability of the operator connecting the headset to the wrong jack, or eliminate the unnecessary jack.

5. Provide a working/writing table for the operator.

6. Increase key spacing to conform to MIL-STD-1472B (36).

7. To improve the CCU operation during missions, the keyboard should be redesigned on the basis of expected frequency and sequence of use data.

IMPLICATIONS OF HUMAN PERFORMANCE TESTS

The introduction to this report explained why it is necessary to have HFE testing in materiel development programs and showed how DI-H-1334A systematically and effectively incorporates HFE data into the Army's materiel acquisition cycle. Succeeding chapters gave details of how to conduct and report HFE tests, with two complete sample test reports showing how tests should be conducted to meet DI-H-1334A requirements. However, the HFE test report is just one part of the entire system development program, and it must be integrated into that program effectively. The paragraphs in this section consider how HFE test data should be used, when HFE tests should be conducted, and what problems should be expected in conducting these tests.

HFE Data in the Materiel Development Program

System reliability is often defined narrowly (e.g., 59, p. 1) as a combination of the reliability of the hardware components. This definition of reliability follows naturally when a system is defined for a contractor in terms of the deliverable items of equipment. However, the user defines the system to include not only the equipment, but also the personnel who operate and maintain the equipment and their training. Thus the user is concerned with the field effectiveness of the man-machine system which includes not only the reliability, maintainability, and availability of the equipment but also the capabilities of the personnel to operate and maintain the equipment within prescribed time limits and acceptable error rates. Clearly, any attempt at effectiveness assessment which does not include the human element is likely to be incomplete and to produce an inflated estimate of the effectiveness of a system.

The human factors test is that step of the development program which measures the operator's performance. It has two purposes: (1) to assess what the human operator's performance contributes to overall system performance, and (2) to identify the causes of human error or substandard performance. Thus, the test data are used directly in calculating indices of reliability (failure rate, mean time between failures, time to repair, etc.), as well as indices of effectiveness (accuracy, throughput rates, etc.). Indirectly, HFE data provide a means of identifying and correcting the causes of human performance problems and errors. The HFE test report analyzes human performance empirically in terms of performance times and error rates, and it gives qualitative descriptions of the factors that contribute to errors and slow performance times.

But merely describing the factors that produce errors -- such as insufficient training for Task X, inappropriately allocating Function Y to the human operator, or improperly placing Display Z -- is not enough. Identifying an error is only the first step in eliminating it or reducing its frequency. If the HFE test report is to make an effective contribution to the system development program, it must also suggest ways the observed problems or errors can be solved or corrected. To be most effective, the report should provide several alternative solutions and estimate how effectively they can alleviate the problem. Engineering and cost analysis personnel can then evaluate the alternative solutions and give the program

management the information needed to make a decision.

The stage of system development also affects how HFE data will be used. In the experimental prototype phase, testing focuses on establishing whether human performance is feasible. Data from early testing -- frequency and sequence of use, and criticality of equipment components -- is used to evaluate how appropriately functions have been allocated, and to lay out the workspace. Time and error data from early testing can be used for preliminary estimates of human reliability and system effectiveness. Figure 21 shows that, as system development progresses, more and more parameters are measured empirically and used to derive reliability and effectiveness estimates. In addition, as shown in Figure 22, progressively more confidence can be placed in these estimates as development proceeds. The more input parameters that are measured, the more accurately system effectiveness can be predicted.

In the later stages of system development, testing focuses on assessing the operator's ability to perform his assigned tasks. Time and error data, and the factors that predisposed the operator to err, are used in estimating human reliability and trading off alternative ways of eliminating factors that predispose the operator to err. It is necessary to quantify error rates and list the alternative solutions before their costs can be traded off against the improved system effectiveness they offer.

Scheduling Human Performance Testing During System Development

Figure 23 shows the potential impact that human factors design and testing can have at different stages of system development. Not surprisingly, it costs progressively more to make HFE changes in later stages of development. Yet changes recommended during later development are also more likely to improve system effectiveness, since they are based on more precise data. Unfortunately, the probability that the program manager will adopt recommended HFE changes decreases as the design becomes defined more rigidly.

Figure 23 also shows that the most cost-effective time to detect and correct human errors or substandard performance times is early in the development cycle. Army leaders understand this relationship (54,55), and it can be expected that cost effective HFE tradeoffs will become a more prominent feature of system development in the future. Human factors testing produces the most cost-effective problem solutions when it is done in the experimental-prototype stage, because it is economical to redesign equipment before hardware has been constructed. These design modifications are one-time costs; whereas, the cost of upgrading selection and training continues throughout the life of the system.

Although human factors testing must be conducted early in system development to produce timely recommendations for economic rectification of human performance problems, HFE testing will also be required in later system testing. HFE tests in "advanced development" and "engineering development" are conducted with personnel and equipment which are more representative of operational conditions. HFE tests in later developmental

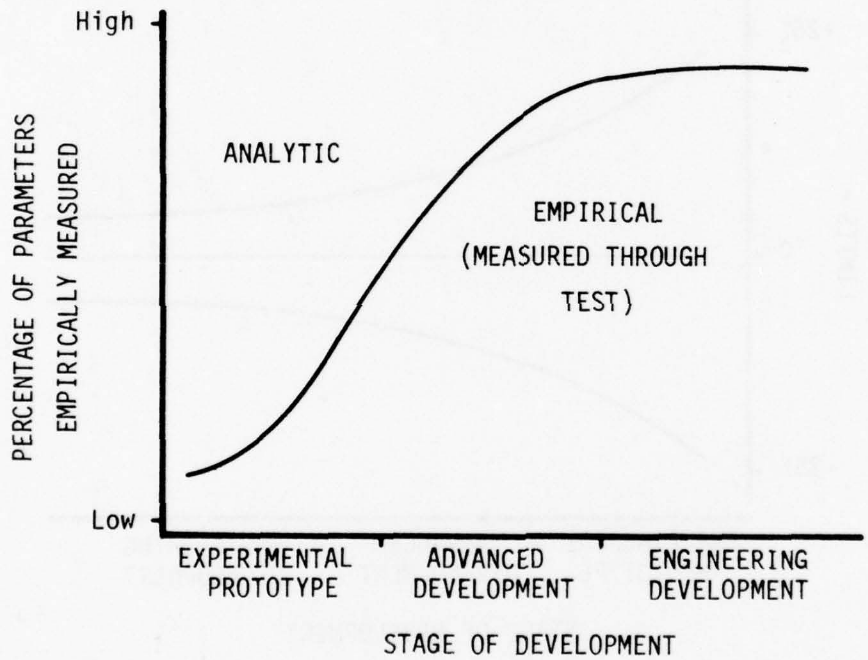

Figure 21. Performance parameters measured during system development

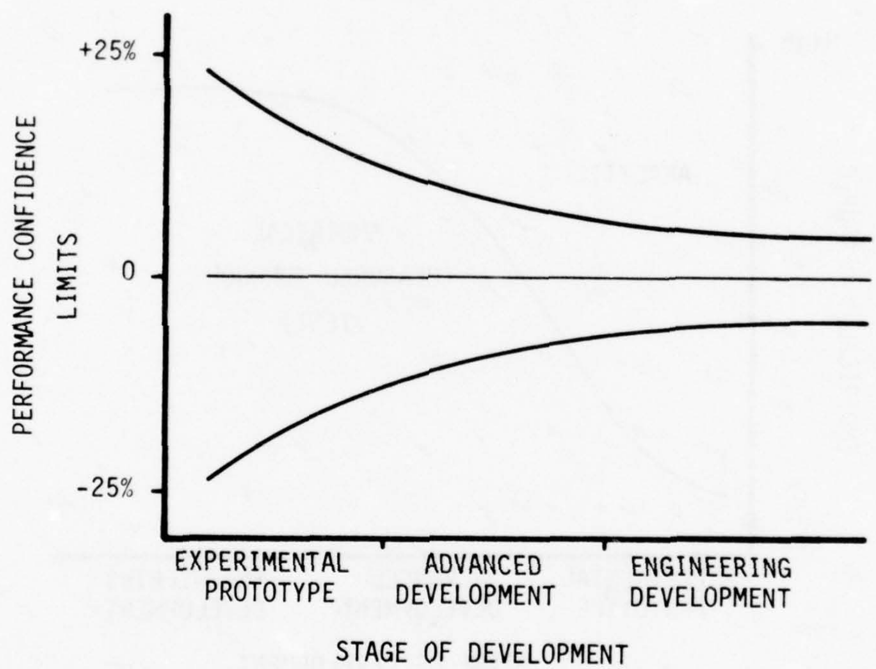

Figure 22. Confidence limits of performance measured during system development

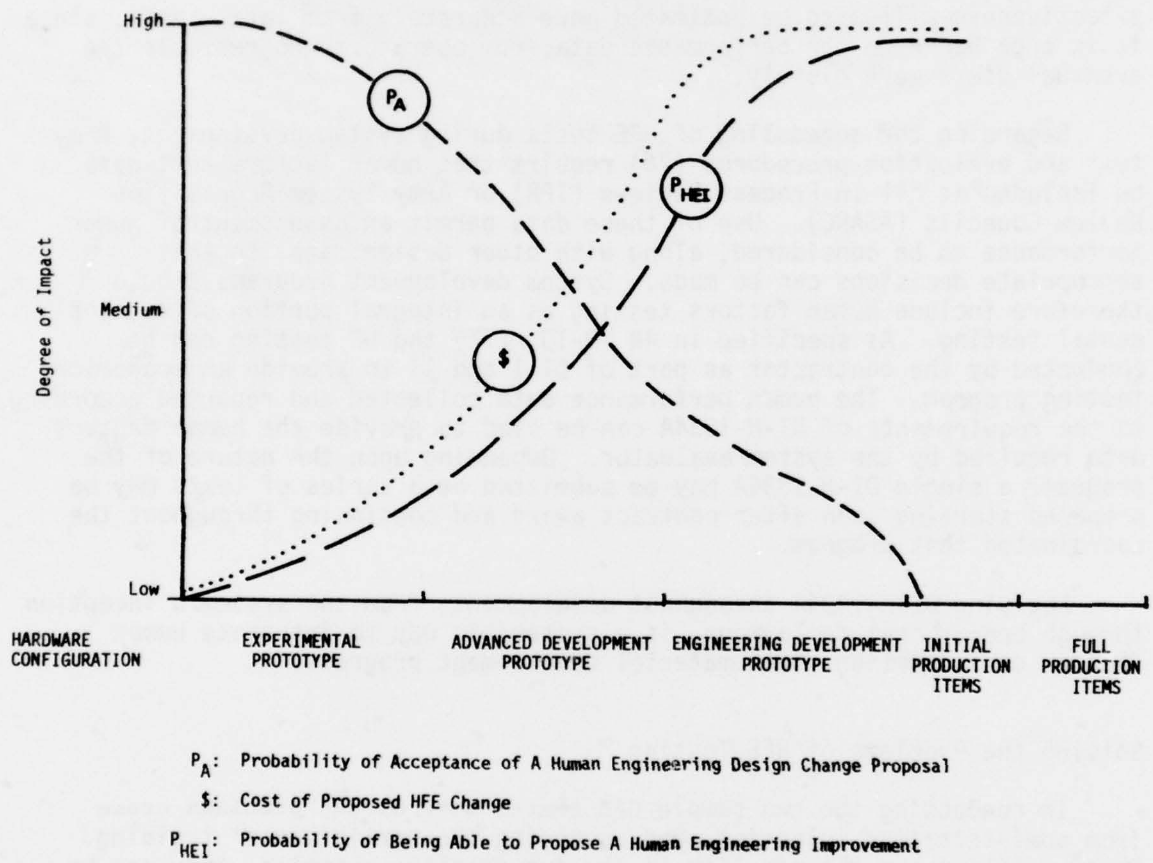

Figure 23. Relationships among P_{HEI}, P_A, and cost

stages are also necessary to determine the adequacy of personnel selection and training. Earlier HFE tests may be able to provide little data with regard to the appropriateness or completeness of selection or training, particularly for an entirely new system, since training and selection programs may not be completely defined prior to DT II. Therefore, later HFE tests will highlight potential deficiencies which may not have been observable in the earlier tests. As implied by Figure 20, the effects of expected use conditions, such as environmental conditions, can be most accurately assessed in HFE tests in later stages of development. System effectiveness will also be estimated more accurately from later tests, since it is then based on the performance data from operators who resemble the eventual users more closely.

Regarding the scheduling of HFE tests during system development, Army test and evaluation procedures (76) require that human factors test data be included at all In-Process Reviews (IPR) or Army System Acquisition Review Councils (ASARC). Use of these data permit an assessment of human performance to be considered, along with other design data, so that appropriate decisions can be made. System development programs should therefore include human factors testing as an integral portion of developmental testing. As specified in AR 70-10, (76) the HF testing can be conducted by the contractor as part of DT I and II to provide an economical testing program. The human performance data collected and reported according to the requirements of DI-H-1334A can be used to provide the human factors data required by the system evaluator. Depending upon the nature of the program, a single DI-H-1334A may be submitted or a series of tests may be prepared starting soon after contract award and continuing throughout the coordinated test program.

Applying DI-H-1334A throughout development, from the system's inception through operational deployment, is a systematic way to integrate human factors considerations into materiel development programs.

Solving the Problems of HFE Testing

In conducting the two sample HFE tests, most of the problems arose from administration, planning, and assessing the participants' training. These problems are not peculiar to the two specific examples; they can be expected to occur unless precautions are taken to prevent them. Hence, the problems the authors encountered, and the solutions that were developed, will be described briefly here.

The main administrative problems in implementing DI-H-1334A were coordinating all of the management and technical personnel, and scheduling the test milestones. These problems are like those of coordinating any test for a multidisciplinary materiel development program. They included activities such as gathering descriptions and drawings of equipment from engineering departments, obtaining definitions of system goals and descriptions of system operation from system analysis personnel, and scheduling the construction or acquisition of test equipment.

A good solution for the problems of administration is to appoint a single person as test manager with overall responsibility for the HFE test (even if this person also has other responsibilities in the materiel development and testing program). The centralization of responsibility for human factors testing in one person will facilitate planning and coordination. The test manager should have the knowledge and experience to carry out the tasks of a manager of a small project (1). The test manager should also have sufficient technical knowledge and experience in human factors testing to be able to perform or direct all of the activities shown previously in Table 1.

Planning the HFE test is a major activity. Thus, the test manager contributes significantly to the success of the test by the manner in which he plans the test activities. It is important to schedule DI-H-1334A test activities carefully to avoid major problems. The checklist previously illustrated in Table 1 provides a systematic sequence of activities that must be scheduled. The following items must be completed prior to testing to insure that all scheduled activities occur in a timely manner:

1. Mockups must be prepared and checked out sufficiently in advance to permit whatever layout changes are found to be necessary.

2. All necessary test equipment and instrumentation must be obtained and calibrated.

3. Test scenarios need to be developed and verified.

4. Preplanning at the test location is essential, including test dry runs to assure that:

    a. all instruments function correctly,

    b. test personnel understand what they are supposed to do in obtaining and recording test data,

    c. test personnel can see what is happening and record data without interfering with test participants.

Selecting and screening the participants can be troublesome, particularly in early-development phases when the training and selection criteria have not been defined completely. Nevertheless, it is essential to use adequately trained participants, since poorly trained operators can make the system seem much less effective than it actually is.

The intent of DI-H-1334A is to use test participants who resemble, as closely as reasonably possible, the eventual system personnel. Thus, efforts must be made to measure the capabilities of the test participants with respect to those characteristics deemed necessary for the eventual personnel (12). In addition to basic capabilities, such as intelligence and visual acuity, the test participants' training must be assessed. The measurement of this training appears to be one of the most difficult problems in conducting a DI-H-1334A test and can best be solved by preparing testing

materials or short job tests which adequately measure the participants' abilities to perform the essential tasks identified in the task analysis. The results of these tests will determine the proficiency of the test participants and indicate any need for refresher training before the HFE testing begins. If the training tests or expert opinion indicated the test participants are not sufficiently prepared to operate or maintain the system equipment properly, extra time must be allocated to provide sufficient refresher training.

Human Factors in System Development

Normally, the person operating the system doesn't want to make mistakes, and it is the design of the equipment which sets his basic error frequency (41). It has been reported that 50 to 70 percent of all failures in major weapons and space systems are human initiated, placing "human error ahead of design error, component unreliability, and lapses in quality control in manufacturing..." (15). Clearly, it is important for successful system operation to identify the sources of human error and to provide solutions for eliminating the errors as soon as possible in the system development program.

Human factors personnel can provide timely analyses and design recommendations with regard to the required human performance, the personnel selection and training procedures, and the man-machine interface design. However, human factors tests must be conducted to answer the questions "How well does the equipment perform in the hands of the soldier in the field?" Data item DI-H-1334A provides a systematic methodology for including human factors data throughout a system development cycle. Properly used at the appropriate times, this data item provides a cost-effective method for evaluating and improving human performance contributions to overall system effectiveness.

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APPENDIX 1

CCU OPERATIONS TRAINING TEST

Subject ___________

Date ___/ ___/ 76   Time ________

CCU OPERATORS TEST

1. How many subscribers are possible with the CCU?

DDT	Wire	Radio	Local
4	8	8	10
8	10	16	16
10	32	20	20
16	40	32	32

2. What is the <u>maximum</u> number of subscribers that can be included on <u>one</u> net?

DDT	Wire	Radio	Local
1	1	1	2
2	4	3	8
4	6	6	10
6	10	8	20

3. Can an AM radio and an FM radio be connected to the same net?

   True   False

4. How many nets can be set up on the CCU? (Don't count the net which holds the unassigned subscribers.)

5. On what net are unassigned subscribers parked?

6. The intercom (COM) is used primarily to communicate with

   DDT
   Wire
   Local
   Radio
   RCMU

7. The operator circuit is used to answer calls from all of the following subscribers <u>except</u> one. Identify the one <u>exception</u>.

   Wire
   Local
   Radio
   RCMU

8. List all five types of circuits available on the CCU.

   1.

   2.

   3.

   4.

   5.

9. Digital data traffic can be transmitted through the CCU only in the AUTO mode.

   True False

10. List the sequence of buttons pressed to put the following subscribers on link 3. (Put the subscribers on the link in the following order:)

    1. Wire 1
    2. Wire 5
    3. Radio 2
    4. Local 5
    5. Local 8

11. The following displays are flashing:

    RING 2

    RAD
    RING 2 3

    LOCAL STATUS/RING 19

    List the sequence of buttons pressed to answer the ring from Radio 3.

    Now list the sequence of buttons pressed to answer Local 19.
    (Remember you had responded to Radio 3 just before answering Local 19.)

12. WIRE 7, RADIO 2, and LOCAL 8 are connected on Link 1. What happens if WIRE 7 rings in on the link?

    1. Wire 7 is disconnected from Link 1.
    2. RING display shows 7
    3. All subscribers on Link 1 are disconnected.
    4. None of the above.

13. On what circuit is a subscriber located after the CCU operator presses ANS?

14. On what circuit is a subscriber located after the CCU operator presses OPR and DISC?

15. Power to the RCMU is:

    a. Provided by a 28 volt nickel cadminum battery.

    b. Provided by the CCU.

    c. RCMU is a passive monitoring device; no power is provided to it.

    d. 28 volts AC at J1.

16. When power is turned on at the CCU, blinking error code 88 indicates that:

    a. Ring in and data control processing is ready to be processed.

    b. Self-test passed successfully.

    c. Net files are filled.

    d. Link files are filled.

17. If prime power coming from the PCG to the CCU were lost:

    a. The CCU would remain fully operational for at least ten minutes.

    b. The CCU memory would retain the Net and Link set-ups for ten minutes.

    c. Error code 84 will blink continuously for ten minutes.

    d. The RCMU will continue to function because it is a passive device.

18. The maximum number of Radio subscribers per net are:

    a. 6 Radios, AM and/or FM.

    b. 3 Radios, AM only.

    c. 3 Radios, FM only.

    d. 3 Radios, AM and/or FM.

19. Which of the following is not a communication capability of the CCU?

    a. Manual cordless switchboard.

    b. Local Intercom.

    c. Integrated Multi-Media nets.

    d. Integration Net-Link facility.

20. When establishing wire communication between CCU's:

    a. KEY ON must be used at both CCU's.

    b. Only local subscriber circuits are used.

    c. KEY ON is required if trouble is experienced with polarity.

    d. Local subscriber circuits may be used if they are BOX circuits.

21. The major units of the CCU Central Logic Unit are:

    a. IOU, CPU, ROM, RAM.

    b. Timing Unit, Central Processing Unit, CCU Analog Card Interface.

    c. Timing Unit, CPU, IOU.

    d. Timing Unit, IOU.

22. To move Net 2 Local Subscriber 10 to Net 3 the most logical keyboard sequence would be:

    a. NET, 2, LCL, 10, DISC, NET, 3, CONN.

    b. NET, 2, LCL, 1, 0, DISC, NET, 3, LCL, 1, 0, CONN.

    c. NET, 3, LCL 1, 0, CONN.

    d. CONN, NET 3, LCL, 10.

23. To disconnect NET 2 from the CCU the operator would depress the following switches:

    a. NET, 2, OP, DISC, DISC, DISC

    b. NET, 2, DISC, DISC, DISC

    c. NET, 2, WIRE 2, DISC, RAD 2, DISC LOCAL 2, DISC

    d. NET, DDT 2, DISC, RAD 2, DISC, LOCAL 2, DISC WIRE 2 DISC

24. To connect a Radio subscriber to a net the operator would take the following key sequence:

    a. RADIO NO. NET. NO.

    b. NET, NO, RADIO NO.

    c. RADIO, NO, NET, NO. CONN.

    d. NET, NO, RADIO, NO. CONN.

25. Whenever the NET Window in the display is not blank or zero the following switches may be depressed:

    a. MON, TALK, OFF.

    b. MON, TALK, OFF, XMIT.

    c. MON, TALK, OFF, XMIT, MAN and AUTO.

    d. MON, TALK, OFF, MAN and AUTO.

26. The RCMU can monitor:

    a. 8 nets.

    b. 7 nets and one local line.

    c. 6 nets, a local line, and an intercom line.

    d. Only one net at a time.

27. The KEY ON feature is indicated by a decimal point to the right of the respective:

    a. Local subscriber.

    b. FM radio subscriber.

    c. AM radio subscriber.

    d. Wire subscriber.

28. The intercom circuit is:

    a. Used between the CCU operator and local subscribers.

    b. A 5-party line with 4 RCMU's and a CCU.

    c. Used in conjunction with the Operator circuit to make calls to the FO's.

    d. Essentially a one-way circuit.

29. Power up on the CCU initiates:

    a. A cold start test of the CCU and RCMU.

    b. An initialization self-test and then a cold start self-test of the CCU.

    c. An initialization self-test of the CCU and RCMU.

    d. A cold start test of the multi-media nets only.

30. The maximum number of local telephone subscribers on any one net are:

    a. 8 VOX

    b. 20

    c. 12

    d. 6 on two wire

APPENDIX 2

SAMPLE BEHAVORIAL CHECKLIST
(CCU Test Segment 4)

TEST SEGMENT 4

CCU OPERATIONS

SUBJECT NAME_______________________________

DATE_____________ START TIME_________ END TIME___________

TASK	INFORMATION	INFO MODE	TIME	ACCURACY CORRECT	ERROR DESCRIPTION
1. Verify selected connections					
(a) B_N Cmdr.	RAD, 5, RING, OPR, DISC				
(b) S_2	WIRE, 4, RING, OPR, DISC				
(c) COMMO	WIRE, 7, RING, OPR, DISC				
(d) DIV/ARTY	WIRE, 1, RING, OPR, DISC				
(e) FOX	RAD, 1, RING, OPR, DISC				
(f) MASIT	WIRE, 8, RING, OPR, DISC				
(g) MESS	LCL, 2, RING, OPR, DISC				
(h) SECURITY	LCL, 5, RING, OPR, DISC				
(i) STATION 6	LCL, 15, RING, OPR, DISC				
2. Verify Nets					
(a) Net 1	WIRES 1,2 RADIO 5,9 DDT 1				
(b) Net 2	WIRE RADIO 10 DDT 2				
(c) Net 3	WIRES 4,7 RADIO 4 DDT 3 LCL 5				
(d) Net 4	WIRES - RADIO 1 DDT 4 LCL 6,7, 15				
(e) Net 5	WIRE 30,31 RADIO 2 DDT 5 LCL 3,4,8,16,17				
(f) Net 6	WIRE 8,32 RADIO 3 DDT 6				
(g) Net 7	WIRE 3,5,6 RADIO 6,7,8 DDT 0				
3. Set up link between Bn CDR - Security	Ans Ring in from RAD 5, Link, 1, RAD 5, CONN, LCL, 5, CONN				
4. Radio 1 rings in requests to put on CF net -- advise ACL	NET, 1, RAD, 1, CONN				
5. Verify nets in question and update data sheet	NET, 1 WIRE 1,2 RADIO 1,59 DDT 1 Nets displayed compared to operation sheet NET, 4 WIRE -- RADIO - DDT 4 LCL 6,7,15				
6. COMMO rings in and requests a link -- link COMMO, RADIO 1, Station 6	LINK, 1, WIRE, 7, CONN, RAD, 1, CONN, LCL, 15, CONN				
7. Mess Sgt. rings in, link mess with station 6	LINK 2, LCL, 2, CONN, LCL, 15, CONN				
8. Station 6 rings in. Put me back on Link 1.	LINK, 1, LCL, 15 CONN				
9. S2 rings in. Asks time of day	ANS. OPR. DISC.				
10. DIV/ARTY calls in place on BGD-FSD Net. Advise ACC	ANS, WIRE, 1. NET, 3, WIRE, 1, CONN				

TEST SEGMENT 4 (CONTINUED)

SUBJECT NAME______________________________

DATE______________ START TIME_________ END TIME___________

TASK	INFORMATION	INFO MODE	TIME	ACCURACY CORRECT	ERROR DESCRIPTION
11. Verify Nets Net 1 Net 3	 WIRE 2, RAD 1, 5, 9 DDT 1 WIRE 1,4,7 RAD 4 DDT 3 LCL 5				
12. Monitor S2 Talking on FSO Net	NET, 3, MON				
13. FDO tells CCU to DISC LINK 1	LINK, 1, TALK -- TELL EACH SUB TAKING THEM OFF LINK LINK, 1, DISC, DISC, DISC				
14. Reconfigure Nets Power Off Net 1 Net 2 Net 3 Net 4 Net 5 Net 6 Net 7	 WIRE 2, RAD 1, 5, 9 DDT 1 RAD 10 DDT 2 WIRE 1, 4, 7 RAD 4, DDT 3 LCL 5 DDT 4 LCL 6, 7, 15 WIRE 30, 31 RAD 2 DDT 5 LCL 3,4,8.16,17 WIRE 8,32 RAD 3 DDT 6 WIRE 3,5,6 RAD 6,7,8 DDT				
15. FDO tells CCU to add Stations 9, 10 on CCU net.	Net, 2, LCL 18, CONN, LCL, 19, CONN				
16. Verify Connection Net 2	RAD 10 DDT 2, LCL 18, 19				
17. DIV/ARTY calls in Link DIV/ARTY, MASH MASH rings OFF	ANS LINK, 1, WIRE 1, CONN, WIRE 8, CONN				
18. LINK DIV/ARTY with Station 6 -- Do not ring off.	LINK, 1, WIRE 1, CONN, LCL 15, CONN				
19. BN CDR calls in requests DIV/ARTY on CC NET.	ANS NET, 1, WIRE, 1, CONN				
20. FDO requests to COMM N/ RCMU 1, and RCMU 2	COM, 2, RING, 3, RING				
21. FDO requests that security feed in a data tape. CCU put in manual mode and monitor traffic	LCL, 5, RING Get Data Ready				
22. FDO ready Transmit Data	XMIT DATA				
23. Monitor Data	NET, 3, MON				

TEST SEGMENT 4 (CONTINUED)

SUBJECT NAME______________________________

DATE______________ START TIME__________ END TIME___________

TASK	INFORMATION	INFO MODE	TIME	ACCURACY CORRECT	ERROR DESCRIPTION
24. BN CDR calls in Net 1 DDT DONN, exchange with F3 Net 6	ANS NET, 1, DDT, 1, DISC, DDT, 6, CONN NET, 6, DDT, 1, CONN				
25. Verify Nets Net 1 Net 6	 WIRE 1,2 RAD 1,5,9 DDT 6 WIRE 8,32, RAD 3 DDT 1				
26. Call in from MASH DISC. from Net 6	ANS NET, 6, WIRE, 8, DISC				
27. Verify MASH Off Net 6 Net 6 Net 9	 WIRE 32 RAD 3 DDT 1 WIRE --- 8				
28. COMMD Calls in Connect with Div CDR DIV/ARTY Tells DIV/ARTY to put Div CMD on Net 3	ANS WIRE, 1, RING				
29. MON link between COMMD & DIV CMD	Net 3, MON Cannot monitor a link				
30. Station 6 calls in Put me on FOX 1 RADIO and Ring me on LCL	ANS ANS Changes CTB Connections Puts Station 6 on LCL 14				
31. Ring up Station 6	LCL, 14, RING				
32. Connect Station 6 to FOX 1 Net	 NET, 4, LCL, 14, CONN, LCL, 15, DISC.				
33. Verify Net 4 Net 4	 DDT 4 LCL 6,7,14				
34. FDO requests the following be put on Net 8: F1, BN, CMD, DIV/ARTY, S2, COMMO, MASH, MESS Security and Station 6 and DDT 4	NET, 8, RAD, 1, CONN, RAD, 5, CONN, WIRE, 1, CONN WIRE, 4, CONN, WIRE, 7, CONN, WIRE, 8, CONN, LCL, 2, CONN LCL, 5, CONN, LCL 14, CONN, DDT, 4, CONN				
35. Power Down Reconfigure Nets Net 1 Net 2 Net 3 Net 4 Net 5 Net 6 Net 7 Net 8	 RAD 9 WIRE 2 DDT 6 RAD 10 DDT 2 LCL 18,19 RAD 4 DDT 3 LCL 6,7 RAD 2 WIRE 30,31 DDT 5 LCL 3,4,8,16,17 RAD 3 WIRE 32 DDT 1 RAD 6,7,8 WIRE 3,5,6 RAD 1,5 WIRE 1,4,7,8 LCL 2,5,14 DDT 4				
36. Verify Nets					

APPENDIX 3

SAMPLE TEST PARTICIPANT QUESTIONNAIRE

PARTICIPANT QUESTIONNAIRE

1. PERSONAL DATA

Participant Number ________________ Date ______________________

Age _________ Height _____________ Weight ____________________

Years in Service __________________ Grade _____________________

Time in Grade ______________ Duty Assignment __________________

Weeks of Experience in Duty Assignment _________________________

Visual Acuity _________________ AGCT Score ____________________

Any Physical Disabilities ______ If Yes Indicate Type __________

2. EXPERIENCE

Schooling (Circle highest year completed)

Grade School	Jr. High School	High School	College
1 2 3 4 5 6	7 8 9	10 11 12	1 2 3 4 5 6

Service Training:

List all service schools attended and months in each.

Weeks of Experience Operating CCU ______________________________

3. ANTHROPOMETRIC DATA (Sitting)

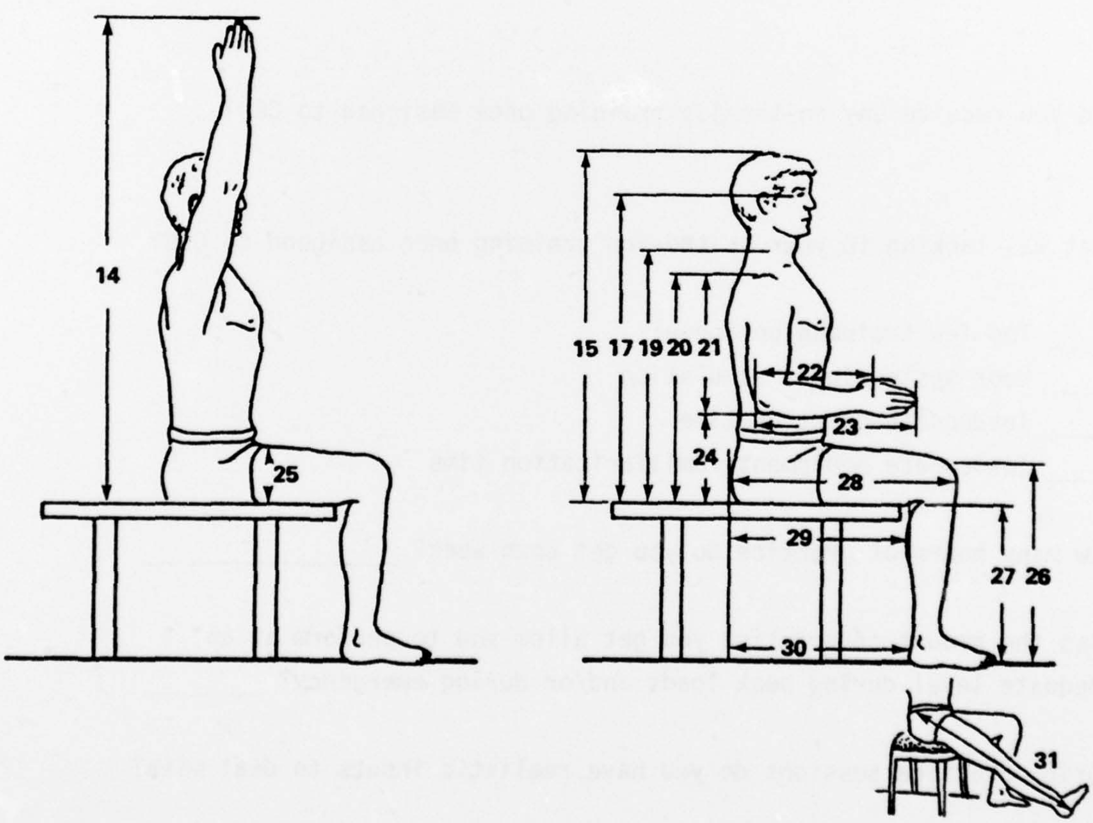
(15) Sitting Height____________________(17) Eye Height________________

(24) Elbow Resting Height____

Horizontal Arm Reach___________(14) Vertical Arm Reach__________

(23) Elbow-Fingertip Reach__________(31) Buttock-Heel Length__________

4. UNUSUAL CLOTHING (other than fatigues)



1. In what general ways could the CCU Training program have better prepared you for your present task?

_____ More practice on real equipment
_____ Better simulation of real equipment
_____ More extensive theoretical background
_____ More extensive operational lectures
_____ More detail on all aspects of training
_____ Other, specify:

2. What specific aspect of your task could be improved by additional training?

3. Did you receive any on-the-job training once assigned to CCU?

4. What was lacking in your on-the-job training once assigned to CCU?

_____ Too few training personnel
_____ Poor system input simulation
_____ Inadequate practice time
_____ Inadequate equipment familiarization time

5. How many hours of practice do you get each week? _______________

6. Does the amount of practice you get allow you to perform at an adequate level during peak loads and/or during emergency? ________

7. During practice sessions do you have realistic inputs to deal with?

8. You have been trained (formally or otherwise) to perform a particular sequence of tasks in order to operate your console. In what ways do you deviate from this sequence in order to perform more effectively?

9. Do you find the task of operating the CCU uninteresting and dull? _____

10. Would you rather operate a different console? ______________________

11. While working at your console, when do you begin to feel bored? __________(minutes). How about fatigued? __________(minutes). When do you think your "being tired" began to affect your efficiency on the equipment? ____

12. Do you ever have difficulty knowing when to start your task? __________ If yes, please explain the problem.

13. If given the opportunity, in what ways would you change the placement of certain console displays, knobs, dials, etc.?

14. If given the opportunity to change the placement of the console, where would you put it relative to other operational equipment?

15. Please list any display interpretation, dial or indicator reading problems, or control utilization problems which you frequently have in performing your task.

Display or Control	Problem	Cause of Problem (e.g., placement, scale info., rate, knobs too close, etc.)

16. Listed below are some factors which might cause an operator to perform at a level lower than his best. Check those which cause you difficulty and explain the problem it causes.

_____ Environment too dark _____________________________

_____ Environment too bright _____________________________

_____ Too much glare _____________________________

_____ Environment too cool _____________________________

_____ Environment too warm _____________________________

_____ Environment too noisy _____________________________

_____ Environment too crowded _____________________________

_____ Seats uncomfortable _____________________________

_____ Not enough fresh air _____________________________

_____ Console lighting too low _____________________________

_____ Console lighting too bright _____________________________

_____ Others (please specify) _____________________________

17. What mechanical aspects of the equipment did you have difficulty with during operation?

a. Activating switches	f.
b. Discerning information on display	g.
c. Writing on forms	h.
d. Reaching equipment	i.
e. Access to operating position	j.

18. Which task or sequence of operations did you have difficulty in performing?

a. Start up	e. Net changes
b. CTB connections	f.
c. Net set up	g.
d. Card replacement maintenance	h.

What do you think the reason for this difficulty is?

a. Layout of the equipment
b. Infrequency of such operations
c. Complexity of such operations
d. Inadequacy of instruction
e. Other

19. Were you able to maintain a comfortable position during operation?

a. yes　　b. no

20. Did you have to strain yourself frequently to reach all the controls?

a. yes　　b. no

21. What, in your opinion, should be the maximum length of time an operator spends on duty?

a. 2 hrs
b. 4 hrs
c. 6 hrs
d. 8 hrs
e. 10 hrs
f. 12 hrs

22. Has the design of any TACFIRE equipment hindered your ability to operate (or to perform maintenance) effectively?

23. Has the design of any TACFIRE equipment caused you to make an error or misinterpret an output during operation of the system?

24. Have any environmental conditions hindered efficient operation and maintenance?

25. Have noise levels interfered with normal operations at any time?

26. Has there been any damage to equipment or loss of data as a result of improper actions or improper interconnections of components?

27. What criticisms do you have of the equipment layout, and what suggestions do you have to improve your effectiveness as an operator?

APPENDIX 4

SAMPLE HFE CHECKLIST

HUMAN FACTORS CHECKLIST -- OPERATION

		YES	NO	N/A
1.	Are noise levels generated by components interfering with personnel speaking at conversational levels?	___	___	___
2.	Is adequate space provided for each operator in front of his respective equipment?	___	___	___
3.	Can each operator leave his working position and the compartment without disturbing any other operator?	___	___	___
4.	From their operating positions, can supervisors observe all the personnel in the compartment under their charge?	___	___	___
5.	Are ladders, climbing rings, hand-holds, and rails, walkways, etc., present where needed and are they adequate enough to provide sure footing and gripping even when icy or highly waxed?	___	___	___
6.	Are mechanical and electrical interlocks provided to prevent turning equipment on, or moving it, when men are in positions which would be dangerous?	___	___	___
7.	Is writing space provided where tasks involve the use of books, manuals, or forms?	___	___	___
8.	Is the CRT display legible during all presentations?	___	___	___
9.	Do all of the operators requiring information from a common display have a clear line of sight from their operating positions?	___	___	___
10.	Is the major display for each operator mounted perpendicular to his normal line of sight?	___	___	___
11.	Are primary controls and displays placed within the optimal visual and manual spaces on the console or unit?	___	___	___
12.	Can a display be read easily from the expected or normal locations of all operators who require the information?	___	___	___
13.	Is parallax on the display minimized for the operator's normal visual axis?	___	___	___
14.	Is there visual flicker on any display?	___	___	___

	YES	NO	N/A
15. Does activating a control obscure a visual display or control markings?	___	___	___
16. Does any equipment design cause operator discomfort, including stress and fatigue?	___	___	___
17. Are emergency controls and displays placed in readily accessible positions?	___	___	___
18. Are emergency controls quickly identifiable for maximum speed of operation?	___	___	___
19. If emergency controls affect the equipment extensively when operated, does it require at least two distinct motions to operate them?	___	___	___
20. Are displays that must be check-read grouped together?	___	___	___
21. Does every control and display on the panel have a descriptive legend associated with it?	___	___	___
22. Is there adequate separation between controls, so that they can be operated easily without accidentally disturbing adjacent controls?	___	___	___
23. When controls must be adjusted as an operator observes a display, can he reach and adjust them easily while viewing the visual display?	___	___	___
24. Are successive control movements interrelated (i.e., does one movement pass easily into the next)?	___	___	___
25. Do controls used in rapid sequence have uniform direction of motion?	___	___	___
26. Are control movements consistent for all of the equipment which one operator uses?	___	___	___
27. Does the method of preventing accidental activation of any control increase the time to operate the control to such an extent that it is unacceptable?	___	___	___
28. If an operator's task is complex, are the controls distributed so that no one limb is overburdened?	___	___	___
29. Are controls associated with similar functions located in the same relative position from panel to panel?	___	___	___

	YES	NO	N/A
30. Are controls of the same size used for performing the same functions on different equipment?	___	___	___
31. Is the operator warned of a failure in the unit?	___	___	___
32. Is overall display area as small as possible, consistent with legibility at the required reading distance?	___	___	___
33. When displays are used sequentially, are they aligned horizontally from left to right, and as close to each other as possible?	___	___	___
34. When the operator must monitor or perform a sequence of operations, are the displays arranged in the actual order of events?	___	___	___
35. Are the most important controls located in front of the operator within easy reach, and between elbow and shoulder height?	___	___	___
36. Can the shapes of controls be discerned both visually and by touch when applicable?	___	___	___
37. Do color controls provide ample contrast with the background?	___	___	___
38. Is color coding consistent with established standards of the system?	___	___	___
39. Is color coding limited to the following six colors: white, black, red, yellow, green and blue?	___	___	___
40. Is information presented in the most immediately meaningful form (no interpretation or decoding required)?	___	___	___
41. Is information displayed to the accuracy required for the operator's decisions or actions, and preferably no more accurately than required?	___	___	___
42. Is information for different types of activities (e.g., operation and maintenance) combined when not necessary?	___	___	___

APPENDIX 5

SAMPLE TEST SCENARIO
(CCU Test Segment 4)

TASK	FDO (Tst Dir)	BN CDR	S2	COMM O.	DIV/ARTY	DIV CDR	RADIO 1	M.A.S.H.	MESS	SECURITY	STA. 6
1	Verify conn. with subs	Answer	Answer	Answer	Answer		Answer	Answer	Answer	Answer	Answer
2	Verify nets and report to ACC opr.										
3		"Link me Security" (1)								Answer & ring off after talk (2)	
4							"Put me on CF net"				
5	Verify nets 1 & 4, update net form										
6				"Link me to Fox 1 & Station 6" (1)			Answer (3)				Answer (2)
7									"Link me to Station 6" (1)		Answer, then ring off (2)
8	Monitor the link			Answer (3)			Answer (2)				"Put me back on link with Comm O & Radio 1" (1)
9			Ring on net. Ask for time of day								
10					"Put me on Bgd. FSO net"						
11	Verify nets 1 & 3, Update form										
12	Monitor all nets		Answer Div/Arty (3)		Talk to S2 on FSO net (1)					Talk on FSO net (2)	
13	Tell Link 1 that you will dis-connect them. Dis-connect Link 1										

TASK	FDO (Tst Dir)	BN CDR	S2	COMM O.	DIV/ARTY	DIV CDR	RADIO 1	M.A.S.H.	MESS	SECURITY	STA. 6
14	Power Off. "Re-config. nets										
15	"Add Sta. 9 to LBU net"										
16	Verify net 2 & update net form										
17					"Link me to M.A.S.H." (1)			Answer "No plasma, call Sta. 6" Ring off. (2)			
18					"Link me to Sta. 6" (1)						Answer, don't ring off (2)
19		"Where's Div/Arty? Put him back on CF net"				Answer					
20		"Exchange my DDT with Fox 3 net"									
21	Verify nets 1 & 6, update form										
22								"Dis-connect me from my net"			
23	Verify net 6 & 9, update form										
24				"Connect me with Div CDR at Div/Arty" (1)	Set up link with BN & Div. Cdr (2)	Answer					
25							"This is Sta 6 calling from Rad 1 Put Sta 6 on a new local connec-tion."				